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DETERMINATION OF CARBON IN SOILS.

A REPORT

OF

EXPERIMENTS MADE IN THE ROTHAMSTED LABORATORY,

BY

R. WARINGTON and W. A. PEAKE.

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ON THE DETERMINATION OF CARBON IN SOILS.

By R. Warington and W. A. Peake.

It has been long recognised that the amount of organic matter present in soils cannot be accurately determined from the loss on ignition. The hydrated silicates contained in soil retain water even when dried at a temperature far exceeding 100°, but part with this water at a red heat. The loss on ignition is thus always in excess of the carbonaceous matter really present. It consequently becomes necessary to determine directly the amount of carbon in a soil whenever an exact measurement is required of the organic matter present.

A series of determinations of carbon in arable soils from the experimental fields at Rothamsted was made some years ago by Mr. F. A. Manning. The methods he employed were oxidation with chromic acid, and combustion with chromate of lead. These methods gave on the whole nearly agreeing results, the combustion process generally yielding a slightly higher proportion of carbon. More recently a considerable number of carbon determinations by the chromic acid method have been made in the Rothamsted Laboratory, chiefly by Mr. P. H. Cathcart. We have ourselves lately examined three methods for the determination of carbon in soil, and propose in the present paper to describe the mode of proceeding adopted, and to give examples of the results.

1. *Oxidation with Chromic Acid.*

This method is recommended by E. Wolff in his admirable "*Anleitung zur chemischen Untersuchung landwirthschaftlich wichtiger Stoffe.*" It consists in treating the soil with sulphuric acid and bichromate of potassium, or by preference with a mixture of sulphuric and chromic acids, the carbonic acid evolved being estimated in the usual way. This method is recommended by Fresenius as an alternative to a combustion of the soil with oxide of copper or chromate of lead. It is apparently the method which has been most generally employed in agricultural investigations.

The mode of proceeding employed in the present case has been quite similar to that directed by Wolff. 10 grams of the finely powdered soil are placed in a flask of about 250 c.c. capacity, provided with a caoutchouc stopper, through which pass two tubes, one for the supply of liquids, the other for the delivery of gas. The soil is treated with 20 c.c. of water and 30 c.c of oil of vitriol; and the whole, after being thoroughly mixed, is heated for a short time in a water-bath, the object in view being the decomposition of any carbonates existing in the soil. Air is next drawn through the flask to remove any carbonic acid which has been evolved. The stopper is next removed, and coarsely powdered bichromate of potassium introduced. In the case of a pasture soil containing 3 per cent. of carbon, 6 grams of bichromate will be found sufficient, a portion remaining undissolved at the end of the experiment. The stopper is then replaced, its supply tube closed by a clamp, and the delivery tube connected with a series of absorbents contained in **U**-tubes. The first of these tubes contains solid chloride of calcium; the second, fragments of glass moistened with oil of vitriol; the third and fourth are nearly filled with soda-lime, a little chloride of calcium being placed on the top of the soda-lime at each extremity. The last-named tubes are for the absorption of carbonic acid, and have been previously weighed. The series is closed by a guard tube containing soda-lime, with chloride of calcium at the two ends.

The flask containing the soil and bichromate is now gradually heated in a water-bath, the contents of the flask being from time to time mixed by agitation. A brisk reaction occurs, carbonic acid being evolved in proportion as the soil is rich in organic matter. The temperature of the water-bath is slowly raised to boiling as the action becomes weaker, and is maintained at that point till all action ceases. As bubbles of gas are slowly evolved for some time, it has been usual in these experiments to prolong the digestion for four or five hours. When the operation is concluded the source of heat is removed, an aspirator is attached to the guard tube at the end of the absorbent vessels, and air freed from carbonic acid is drawn through the flask and through the whole series of **U**-tubes. The **U**-tubes filled with soda-lime are finally weighed, the increase in weight showing the amount of carbonic acid produced. The object of the chloride of calcium placed on the surface of the soda-lime is to retain the water which is freely given up when the soda-lime absorbs carbonic acid. The second **U**-tube filled with soda-lime does not gain in weight till the first is nearly saturated; it thus serves to indicate when the first tube requires refilling. The same tubes may be used several times in succession.

It was found in some preliminary experiments that no increase in the carbonic acid evolved was obtained by substituting chromic acid for bichromate of potassium.

The organic matter of the soil appears to the eye to be completely destroyed by the digestion with sulphuric acid and bichromate of potassium; the residue of soil remaining in the flask when washed with water is perfectly white, or the dark particles, if any, are found to be unaltered by ignition, and therefore to be inorganic in their nature. Under these circumstances considerable confidence has naturally been felt in this method. The complete destruction of the humic matter of the soil does not, however, necessarily imply that the carbon has been entirely converted into carbonic acid. The first doubt on this head we owe to an observation made to one of us by Professor Wanklyn. He pointed out that in other known cases of the action of chromic acid on organic matter the oxidation frequently stopped short of the production of carbonic acid, and that while oxidation with chromic acid apparently led to a complete reaction when the carbon was in the form of graphite, it would probably yield other products than carbonic acid when the carbon existed as a carbohydrate. The doubt thus raised as to the correctness of the results yielded by the chromate method made it desirable to check the work already done by the use of other methods for the determination of carbon.

2. *Oxidation with Permanganate of Potassium.*

In the trials with this method 10 grams of soil were digested in a closed flask with a measured quantity of solution of caustic potash and crystals of permanganate of potassium. The quantity of potash solution finally adopted was 20 c.c., containing 5 grams of potash. 7 grams of the permanganate were found to be sufficient for a soil containing 3·3 per cent. of carbon. Trials were made with various modes of digestion. The plan which answered best was to heat the flask for half an hour in boiling water, and then for one hour in a salt-bath. The flask during this digestion was connected with a small receiver containing a little potash solution, to preserve an atmosphere free from carbonic acid; distillation to a limited extent was allowed during the digestion in the salt-bath. In some experiments the contents of the flask was distilled to dryness in a chloride of calcium bath, but the results obtained by this plan were frequently low and irregular, the caustic potash forming with clay soils a hard mass, which was afterwards attacked with difficulty by dilute acid.

The first part of the operation being completed a caoutchouc stopper carrying a delivery and supply tube was fitted to the flask, which was then connected with the system of **U**-tubes already described. Dilute sulphuric acid was then poured down the supply tube, a water-bath surrounding the flask was brought to boiling, and maintained thus for one hour, after which air free from carbonic acid was drawn through the apparatus, the **U**-tubes containing soda-lime being finally disconnected and weighed.

In the first stage of this method the carbon of the organic matter is converted into carbonate, and probably also into oxalate of potassium

(Wanklyn, *Phil. Mag.* [5], **5**, 466); in the second stage the oxalate is decomposed by the sulphuric acid and permanganate, and the carbon existing, both as oxalate and carbonate, is evolved as carbonic acid, and absorbed by the weighed soda-lime tubes. Both F. Schulze and Wanklyn have employed permanganate of potassium for the determination of organic carbon, but they have preferred to calculate the amount of carbon from the quantity of permanganate consumed; as, however, by so doing everything oxidisable by permanganate is reckoned as carbon, it seems better to make a direct determination of the carbonic acid formed.

From the amount of carbonic acid found we have to subtract that existing as carbonates in the soil, and in the solution of potash used. For this purpose an experiment is made with the same quantities of soil and potash previously employed, but without permanganate, and the carbonic acid obtained is deducted from that yielded in the experiment with permanganate. If the potash used contains organic matter two blank experiments will be necessary, one with potash and permanganate, and one with soil alone.

A further difficulty arises from the presence of chlorides in the materials, which occasions an evolution of free chlorine when the permanganate solution is heated with sulphuric acid. This error occurs also with the chromic acid method, but in that case the quantity of chloride is merely that contained in the soil, which is usually very small; in the permanganate method we have also the chloride present in the caustic potash, and this is often considerable. Corrections for chlorine by blank experiments are unsatisfactory, the amount of chlorine which reaches the soda-lime tubes depending in part on the degree to which the chloride of calcium tube has become saturated with chlorine. It is better therefore to remove the chlorine in every experiment by the plan which Perkin has suggested (*Trans. Chem. Soc.*, 1880, 121), by inserting a tube containing silver foil, maintained at a low red heat, between the flask and the absorbent **U**-tubes.

The amount of carbonic acid yielded by oxidation with permanganate of potassium was found to be considerably in excess of that obtained by oxidation with chromic acid; to ascertain whether these higher results really represented the whole of the carbon present in the soil trials were next made by actual combustion of the soil in oxygen.

3. *Combustion in Oxygen.*

It appeared that the most convenient mode of carrying out the combustion of soil would be to place the soil in a platinum boat, and ignite it in a current of oxygen in a combustion-tube partly filled with cupric oxide. This plan has proved very successful. A wide combustion-tube is employed, about 20 inches long, and drawn out at one end; the front of the tube is filled for 8 inches with coarse cupric oxide, the hind part is left empty to receive the platinum boat. The drawn out end of the combustion-tube is connected with a series of absorbent **U**-tubes, quite similar to those employed for the estimation of carbonic acid in the chromic acid method. Between these absorbent vessels and the combustion-tube we at first inserted a tube filled with 7 inches of the chromate-pumice recommended by Perkin (*Trans. Chem. Soc.*, 1880, 121, 457) for the absorption of nitrous fumes, this tube being kept just sufficiently hot during a combustion to prevent the deposition of water. Latterly we have abandoned the chromate tube, and substituted for the chloride of calcium tube employed to dry the gas a three-bulbed Geissler tube filled with oil of vitriol. The oil of vitriol has proved quite effective in retaining nitrous fumes, combustions of nitrogenous soils made with and without the chromate tube giving closely agreeing results. The wide end of the combustion-tube is connected with a gasholder of oxygen; the oxygen gas is made to pass through a **U**-tube of soda-lime before entering the combustion-tube, to remove any possible contamination of carbonic acid.

In starting a combustion the part of the combustion-tube containing the cupric oxide is brought to a red heat, and oxygen is passed for some time through the apparatus. 10 grams of soil, previously dried, are placed in a large platinum boat, which is next introduced at the wide end of the combustion-tube. The combustion is conducted in the usual manner, a current of oxygen being maintained throughout the whole operation. It is very useful to terminate the whole series of absorbent vessels with a glass tube dipping into water; the rate at which the gas is seen to bubble serves as a guide to the supply of oxygen from the gasholder, the consumption of oxygen varying of course with different soils, and at different stages of the combustion. At the close of the combustion oxygen, or air freed from carbonic acid, is passed for some time through the apparatus to drive all carbonic acid into the absorbent vessels. One experiment can be followed by another as soon as the hind part of the combustion-tube has cooled sufficiently to admit a second platinum boat. The same combustion-tube can be employed for several days, if packed in the usual manner in asbestos.

The presence of carbonates in the soil occasions some difficulty in working the combustion method, as a part of this carbonic acid will, of course, be given up on ignition, and be reckoned as carbon. The simplest mode of meeting this difficulty is to expel the carbonic acid belonging to the carbonates before the combustion commences. We have had but little experience with soils rich in carbonates, the Rothamsted soils containing at most but a very small proportion of chalk. With such soils we have employed the method already made use of by Mr. Manning in his earlier work on the same subject, namely treatment with a strong solution of sulphurous acid. The 10 grams of soil taken for combustion are placed in a flat-bottomed basin, covered with a thin layer of sulphurous acid, and frequently stirred. After a time the action is assisted by a gentle heat. When the carbonates have been completely decomposed the contents of the basin is evaporated to dryness on a water-bath, the dry mass is then pulverised, and removed to the platinum boat for combustion in oxygen. For the action of the sulphurous acid to be complete it is essential that the carbonates should be in very fine powder, even chalk is but imperfectly attacked when present in coarse particles.

A few experiments were made to test the efficacy of this process. Carbon was first determined in the usual way in three soils naturally free from carbonates; chalk, previously ignited at a low heat to destroy organic matter, was then added in quantity equal to 5 per cent. of the original soil. The soil containing the chalk was next reduced to a very fine powder, a quantity of the mixture corresponding to 10 grams of the original soil was treated with sulphurous acid, and the carbon again determined. The percentages of carbon found were as follows:—

Kind of soil.	In original soil.			After addition of chalk and treatment with sulphurous acid.		
	Exp. 1.	Exp. 2.	Mean.	Exp. 1.	Exp. 2.	Mean.
Old pasture	3·21	3·25	3·23	3·24	3·33	3·29
New pasture	2·33	2·32	2·33	2·32	—	2·32
Clay subsoil	0·29	0·29	0·29	0·31	0·30	0·31

Having thus described the methods which we have examined, we will next submit some numerical results obtained by their use.

Comparison of Methods.

A considerable number of soils analysed by the chromic acid method have been lately re-analysed by the combustion method; the results compare as follows:—

Percentage of Carbon found by two methods in Soils dried at 100°.

No.	Kind of soil.	Chromic acid method.			Combustion method.			Yielded by chromic acid if carbon by combustion 100.
		Exp. 1.	Exp. 2.	Mean.	Exp. 1.	Exp. 2.	Mean.	
1	Old pasture	2·85	2·79	2·82	3·58	3·55	3·57	79·0
2	,, ...	2·83	2·79	2·81	3·57	3·53	3·55	79·1
3	,, ...	2·76	2·76	2·76	3·46	3·46	3·46	79·7
4	,, ...	2·74	2·76	2·75	3·37	3·38	3·38	81·4
5	,, ...	2·64	2·54	2·59	3·31	3·36	3·34	77·5
6	,, ...	2·51	2·43	2·47	3·15	3·15	3·15	78·4
7	,, ...	2·40	2·44	2·42	3·09	3·13	3·11	77·8
8	New pasture	1·92	1·93	1·93	2·41	2·40	2·41	80·1
9	,, ...	1·66	1·81	1·74	2·39	2·43	2·41	72·2
10	Arable soil	1·78	1·78	1·78	2·14	2·13	2·14	83·2
11	,, ...	1·21	1·14	1·18	1·40	1·43	1·42	83·1
12	Subsoil	0·28	0·27	0·28	0·37	0·38	0·38	73·7

Of the above soils the arable soils, Nos. 10 and 11, were the only ones containing carbonates in any quantity exceeding a minute trace. The two soils in question were treated with sulphurous acid before combustion, the others not.

All the determinations by the chromic acid method were made by Mr. P. H. Cathcart, with the exception of Nos. 9 and 12, which were executed by another experimenter, and are seen to give distinctly lower results. Excluding these two analyses the relation of the carbon found by the two methods is tolerably constant, the average being 79·9 of carbon found by oxidation with chromic acid for 100 yielded by combustion in oxygen. The results obtained by the chromic acid method thus appear to be very considerably below the truth.

Four typical soils have been analysed by the permanganate, as well as by the chromic acid and combustion methods. The results obtained were as follows:—

Percentage of Carbon found by Three Methods in Soils dried at 100°.

No.	Kind of soil.	Combustion method.	Chromic acid method.	Permanganate method.			Yielded by permanganate if carbon by combustion 100.
		Mean.	Mean.	Exp. 1.	Exp. 2.	Mean.	
2	Old pasture	3·55	2·81	3·26	3·30	3·28	92·4
8	New pasture....	2·41	1·93	2·29	2·30	2·30	95·4
11	Arable soil	1·42	1·18	1·28	1·33	1·31	92·3
12	Subsoil	0·38	0·28	0·34	0·34	0·34	89·5

Oxidation by permanganate thus gives a much higher result than oxidation with chromic acid; but even the permanganate fails to convert the whole of the carbon into carbonic acid, the product with permanganate being on an average of the four soils 92·4 per cent. of that yielded by combustion in oxygen.

Wanklyn states (*Phil. Mag.* [5], **7**, 138) that a temperature of 160—180° is necessary in some cases to effect complete oxidation with permanganate and caustic potash. Such a temperature was found impracticable when dealing with soil, from the action of the potash on the silicates present: hence possibly the low results obtained.

Combustion in oxygen appears from these experiments to be the most satisfactory method for determining carbon in soil, nor is this method on the whole longer or more troublesome than the other methods investigated.

We have further determined the loss on ignition of the four soils mentioned above, with the view of comparing this loss with the amount of organic matter calculated from the carbon actually present. In making this calculation we have taken as the amount of carbon in the soil that found by combustion in oxygen, and have assumed with Schulze, Wolff, and Fresenius that 58 per cent. of carbon will be present in the organic matter of soils. The four soils were heated successively at 100°, 120°, and 150°, till they ceased to lose weight; the loss on ignition in each of these stages of dryness is shown in the following table:—

Percentage Loss on Ignition compared with Organic Matter calculated from Carbon.

No.	Kind of soil.	Loss on soil dried at 100°.			Organic matter at 58 per cent. carbon.
		Between 100° and ignition.	Between 120° and ignition.	Between 150° and ignition.	
2	Old pasture	9·27	9·06	8·50	6·12
8	New pasture......	7·07	6·88	6·55	4·16
11	Arable soil........	5·95	5·70	5·61	2·44
12	Clay subsoil	5·82	5·39	4·76	0·65

The loss on ignition is seen to be in all cases very considerably in excess of the organic matter calculated from the carbon, even when the soil has been dried at as high a temperature as 150°. The error of the ignition method is least in soils rich in organic matter, as, for instance, the old pasture soil in the above table. The error reaches its maximum in the case of the clay subsoil, which contains very little carbonaceous matter, but is naturally rich in hydrated silicates, which part with their water only at a very high temperature.

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U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU.
BULLETIN No. 4.

SOME PHYSICAL PROPERTIES OF SOILS

IN THEIR RELATION TO

MOISTURE AND CROP DISTRIBUTION.

BY

MILTON WHITNEY,
PROFESSOR OF GEOLOGY AND SOIL PHYSICS, MARYLAND AGRICULTURAL COLLEGE;
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FELLOW BY COURTESY, JOHNS HOPKINS UNIVERSITY.

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BULLETINS OF THE WEATHER BUREAU.

No. 1.—Notes on the Climate and Meteorology of Death Valley, California, by Mark W. Harrington, Chief of the Weather Bureau. June, 1892. (Octavo) 50 pp.

No. 2.—Notes on a New Method for the Discussion of Magnetic Observations, by Frank H. Bigelow, Professor of Meteorology. July, 1892. (Octavo) 41 pp.

No. 3.—A Report on the Relations of Soil to Climate, by E. W. Hilgard, Professor of Agriculture and Agricultural Chemistry, University of California. July, 1892. (Octavo) 59 pp.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
WEATHER BUREAU,
Washington, D. C., July 28, 1892.

SIR: I have the honor to transmit herewith a paper entitled "Some Physical Properties of Soils in their Relation to Moisture and Crop Distribution," prepared by Prof. Milton Whitney, of Johns Hopkins University, and to recommend its publication as Weather Bureau Bulletin No. 4. In this connection I would state that this is the second paper of a series on the relations of soils to meteorology, the object of which is to elicit information from specialists, rather than to indicate the views held by the Department on the subjects treated.

Very respectfully,

MARK W. HARRINGTON,
Chief of Weather Bureau.

HON. J. M. RUSK,
Secretary of Agriculture.

LETTER OF SUBMITTAL.

JOHNS HOPKINS UNIVERSITY,
Baltimore, Md., July 1, 1892.

SIR: I have the honor to submit herewith my report entitled "Some Physical Properties of Soils in their Relation to Moisture and Crop Distribution."

The work for the Department has covered a period of only six and a half months and on the soils of Maryland of only a few months longer. Much of this time has necessarily been spent in collecting material and in other preliminary work. The work is to be continued and the physical properties and conditions of these soils will be studied in still more detail.

This report is based partly on my own original work and partly on a generalization of the work of others in this line, as reported in the literature of the day. The limits of this report would not allow of the presentation of even the main facts from which these generalizations have been drawn, which are well known, however, through the admirable writings of Johnson and Storer, or of the views generally held by agricultural chemists as to the cause of the local distribution of plants. It is believed, however, that although these views and generalizations may appear at first sight to differ from the present theory of fertilization, a more careful consideration will show that they supplement rather than conflict with the views commonly held by agricultural chemists.

Very respectfully,

MILTON WHITNEY.

MARK W. HARRINGTON,
Chief of Weather Bureau.

TABLE OF CONTENTS.

SOME PHYSICAL PROPERTIES OF SOILS IN THEIR RELATION TO MOISTURE AND CROP DISTRIBUTION.

INTRODUCTION.

The history of soil investigations forms a very interesting chapter in scientific literature. It has not been many years since it was generally believed that the chemical analysis of a soil would show what class of plants the soil is best adapted to produce, and what elements of plant food are lacking in the soil for the best development of other crops. It was found, by a vast amount of work on the chemical composition of soils and plants, that all soils contain a large amount of plant food, while the relatively small amount removed by crops in a series of years can not be detected by chemical means, although, as the result of injudicious methods of culture during this period, the soil may deteriorate and the yield of crop fall below the limit of profitable cultivation. It was then believed, and it is still held, that only a small proportion of the plant food in the soil is in such a form as to be readily available to plants, and that this may readily revert to an insoluble or unavailable form if it is not quickly used up by plants.

Various solvents have been suggested and tried to determine the amount of available plant food in the soil. Plot experiments with manures and fertilizers have been carried out to ask of the soil the direct question, what amount of available plant food is needed in order to insure a maximum crop.

Some rather anomalous facts have been shown in this work. A plant having a large amount of nitrogen, for example, in its composition, will not necessarily respond to a manuring with this particular ingredient, but will respond readily to a manuring of another substance, of which it uses only a relatively small amount, while other plants, containing a small amount of nitrogen in their composition, will respond readily when manured with this substance, even on the same land. This is supposed to be due to a difference in the feeding capacity of the plants. A plant which responds readily to a nitrogenous manuring one year may respond more readily to a phosphatic manuring on the same soil the next year if the *season* is different. The standard fertilizing materials frequently give a lower yield of crop than is produced where nothing has been added to the soil; and, on the other hand, a very small addition of a fertilizer may increase the crop to an extent out of all proportion to the amount of plant food added to the soil. This is especially true of stable manure and lime.

There has been no satisfactory interpretation, as yet, of much of the work which has been done on the chemical composition of soils and plants, and the results of plot experiments have, in most cases, been very conflicting and uncertain.

The physical conditions of growth have been recognized as of importance, and of controlling importance in many cases, but their influence has hardly been considered in soil investigations. Records have been carefully kept of all the ordinary meteorological conditions and atmospheric changes, but there has been, in most cases, no interpretation of the results; and the results have been given and remain as a mass of unintelligible and seemingly useless figures.

The distribution of our staple crops, according to the meteorological conditions which prevail in the country, has been very ably discussed by Brewer in the tenth census. It is undoubtedly due to these meteorological conditions, rather than to any difference in plant food or in methods of cultivation, that the average yield of grain per acre in the Southern States is only about one-third of that in the North and West. The conditions at the South are more favorable to long continued growth of leafy matter, and it is difficult to check the growth of the plant and make it produce a fair yield of grain. It is only since the introduction of commercial fertilizers, which have hastened the ripening of the crop, that cotton has been successfully grown as far north as the upper counties of North Carolina, and it is only by improved methods of cultivation that the Sea Island cotton has been made to mature within the season which prevails in South Carolina. Temperature, of course, is a very important factor in plant development, and this alone determines the general distribution of many plants, and prevents tropical fruits being produced in the short season of the Northern States. It is not that the soils of Pennsylvania are less rich in plant food than the soils of Florida, or that the plant food is in a different form of combination, but that temperature is the controlling cause in crop production. This is such an every-day matter that it is hardly realized that temperature is such a potent factor in the distribution of crops, and that even our own seasonal changes must have a more important effect on the development of plants than is usually considered. But even over small areas, where the meteorological conditions cannot be very different, the texture of the soils may be so different that they maintain very different conditions of heat and moisture for the growing crops. In these local conditions, moisture seems to be far more important than heat, and the relation of the soil to moisture largely determines the relation of the soil to heat. However potent, therefore, the factor of temperature may be in the general distribution of crops, the relation of soils to moisture, or the amount of moisture they may maintain under existing meteorological conditions, is quite as important a factor in the local distribution and development of plants. The texture of the soil and its condition and treatment have been recognized as of importance in determining crop distribution and development, but there has been no interpretation or expression of these physical conditions of the soil which could be used in the calculation of results of the soil investigations. It is proposed in this paper to show that the physical properties of soils very largely determines the local distribution and development of plants, and to suggest methods for the study and expression of the physical properties and condition of the soil.

A preliminary report of these soil investigations was published in the Fourth Annual Report of the Maryland Agricultural Experiment Station, and this will be freely used in the present paper, as well as some unpublished matter on investigations of a similar character, carried on by the writer at the South Carolina Experiment Station.

In the older agricultural regions of the country in the Eastern and Southern States, especially below the influence of the glacial action, there are many large areas of well marked and very uniform soil conditions, corresponding to different geological formations, where the distribution and production of crops seem to be dependent upon the texture of the soil. There is a certain type of land in certain geological formations which is so coarse and open in texture that it is permitted to remain in pine barrens; there is another type bordering the coast, in a different geological formation, which is well suited to melons and early vegetables; still other types of soil are suited to different grades of tobacco and to wheat and grass.

The agricultural chemist has approached this subject through the study of the chemical composition of soils and plants, and has attempted to explain the distribution of plants through the minute differences in chemical composition or in the form of chemical combination of the ingredients in the soil. The practical farmer, on the other hand, can judge much more correctly of the condition of the land and what it is best fitted to produce, from the general appearance or physical texture and structure of the soil. It is a matter of common experience to him to judge from the texture and general appearance of the soil what crop it is best fitted to produce, and what general treatment should be pursued in the production of the desired crop. He knows that wheat can not be economically produced on light sandy lands, under prevailing climatic conditions, and that no addition of mere plant food will cause a good wheat crop to be produced on such a soil without resorting to irrigation, where the water supply can be controlled, or without first changing the texture of the soil so as to make it more compact and more retentive of moisture, so that it can maintain a more abundant supply of water for the crop. It is a matter of the available water supply maintained by the soil rather than of the available plant food which determines this local distribution of plants. Under the same climatic conditions the wheat land will maintain two or three times as much moisture for the use of the crop as the light sandy lands. If the conditions in the wheat land are normal, and are necessary conditions for the wheat crop, which can not be doubted in view of the number of determinations which have been made, then there is something radically wrong in the light truck land as a wheat soil, and this relation of the soil to moisture becomes as potent a factor as a controlling cause as temperature is in the economical production of oranges, bananas, and pineapples in the Northern States.

It may be objected that not enough importance is given to the chemical side in this treatment of the subject, but if the relation of the soil to moisture is conceded to be a controlling cause in the local distribution of wheat on these two types of soil, as would be claimed in this case by any practical farmer, then this alone is to be considered first, and all changes, treatment, and improvement of the land must be along this line. A farmer is a man of rare experience and observation in these lines, and is to be relied on in matters of fact, however much those of us who are engaged in purely scientific work may disagree with him in deductions from these facts. The facts themselves must be accepted and be the basis for scientific work. How common it is in the improvement of lands to hear of a refractory clay being made more loamy by judicious treatment, and a loose, incoherent sand being made more retentive of moisture.

Now it seems that there must be some explanation, some interpretation, and some expression of this fact that the farmer can judge of the agricultural value of a land and the kind of crop which it can or can not produce, from the general appearance of the land, that is, from the physical texture and structure of the soil. It would seem that this must come through the proper interpretation of the mechanical analyses of soils. The results of the mechanical analyses, as usually given, have little meaning, for there is little or no attempt at the interpretation of the results, and there is no expression of the results which can be used in forming a definite opinion of the character of the land.

It is proposed to suggest here an interpretation of the mechanical analyses of soils which shall explain and define these visible signs upon which the practical farmer bases his judgment of the agricultural value and condition of the soil, and which can be used, in relative terms at least, in the expression of results of soil and plant investigations.

It will be necessary first to discuss some of the fundamental principles upon which this interpretation is based and then to present problems with an application of the principles. The primary conceptions upon which this is based may be briefly stated as follows: The circulation of water in the soil is due to gravity, or the weight of water, acting with a constant force to pull the water downward, and *also* to surface tension or the contracting power of the free surface of water (water-air surface), which tends to move the water either up or down or in any direction, according to circumstances. The ordinary manures and fertilizers change this surface tension, or pulling power, of water.

There is a large amount of space between the grains in all soils, in which water may be held. The rate of movement of the water will depend upon how much space there is in the soil; upon how much this space is divided up, *i. e.*, upon how many grains there are per unit volume of soil; upon the arrangement of the grains of sand and clay; and upon how this skeleton structure is filled in and modified with organic matter.

The arrangement of the grains, and consequently the texture or structure of the soil, may be changed through the effect of the ordinary manures and fertilizing materials, causing flocculation or the reverse.

THE CIRCULATION OF WATER IN THE SOIL.*

The motive power which causes water to move from place to place within the soil consists of two forces: gravity, or the weight of the water itself, and surface tension. Gravity tends to pull the water downward, and acts with a constant force per unit mass of water, neglecting the slight difference due to elevation and to latitude. Surface tension, or the contracting power of any exposed water surface, may move the water in any direction within the soil, according to circumstances. It may act, therefore, with gravity to pull the water down, or against gravity to pull it up. The force of gravity need not be further considered here.

Surface tension is the tendency which any exposed surface has to contract to the smallest possible area consistent with the weight of the substance. If a mass of water is divided, or cleft in two, leaving two surfaces exposed to the air, the particles of water on either surface, which were before in the interior of the mass and attracted from all sides by like particles of water, have now water particles on only one side to attract them, with only a few air particles, comparatively very far apart, on the other side, where formerly was a compact mass of water. All the surface particles of water will therefore be pulled from within the mass of water, and the surface will tend to contract as much as possible, leaving exposed the smallest number of

*Much of the discussion of these underlying principles is taken from a preliminary paper in the Fourth Annual Report of the Maryland Agricultural Experiment Station.

surface particles, and causing a continual strain or surface tension. On any exposed water surface there is always this strain or tension ready to contract the surface when it may.

It is a constant, definite force per foot of surface for any substance at a given temperature. In the case of liquids and solutions, in which we are most interested, it varies with the nature of the liquid and the substance in solution.

This is surface tension; and we have it in the soil as a strain or tension along the free surface of water within the soil, which tends to contract the surface and so move the water from one place to another as it is needed.

There is, on an average, about 50 per cent. by volume of space within the soil which contains no solid matter, but only air and water. This we shall call empty space. In a cubic foot of water there is about half a cubic foot of empty space, but this is so divided up by the very large number of soil grains that the spaces between the grains are extremely small.

When a soil is only slightly moist the water clings to the soil grains in a thin film. It is like a soap bubble with a grain of sand or clay inside, instead of being filled with air. Where the grains come together the films are united into a continuous film of water throughout the soil, having one surface against the soil grains and the other exposed to the air in the soil. As the soil grains are surrounded by this elastic film, the tension on the exposed surface of the water will support a considerable weight, for the soil grains, thus enveloped, are extremely small and have many points of contact around which the angle of the surface is more acute and the film is thicker and is held with greater force.

If more water enters the soil the film thickens, and there is less exposed water surface. If the empty space is completely filled with water there will be none of this exposed water surface, and, therefore, no surface tension. Gravity alone will act and with its greatest force. If the soil is nearly dry there will be a great deal of this exposed water surface, a great amount of surface tension, and, with so little water present, gravity will have its least effect.

The grains in a cubic foot of soil have, on an average, no less than 50,000 square feet of surface area. There is less, of course, in a sandy soil, and more than this in a clay soil. If there is only a very small amount of water in the soil the film of water around the grains will be very thin, and there will be nearly as much exposed water surface as the surface area of the grains themselves. If a cubic foot of soil, thus slightly moistened, and having this large extent of exposed water surface, be brought in contact with a body of similar soil fully saturated with water, in which there is none of this water surface, the water surface in the drier soil will contract, the film of water around the grains will thicken, and water will be drawn from the wet into the dry soil, whether it be to move it up or down, until, neglecting gravity or the weight of water itself, there is the same amount of water in the one cubic foot of soil as in the other. When equilibrium is established there will be the same extent of exposed water surface in these two bodies of soils.

When water is removed from a soil by evaporation, or by plants, the area of this exposed water surface is increased, and the tension tends to contract the surface and pull more water to the spot.

When rain falls on rather a dry soil the area of the exposed water surface in the soil is diminished, and the greater extent of water surface below contracts and acts, with gravity, to pull the water down.

Fertilizers change this surface tension and modify the contracting power of the free surface of water to a remarkable degree, and so modify the power which moves water from place to place in the soil.

The following table gives the surface tension of a solution in water of several of the ordinary fertilizing materials. The surface tension is expressed in gram-meters per square meter, that is, on a square meter of liquid surface there is sufficient energy to raise so many grams to the height of one meter.

Where the substance was sufficiently soluble the solution was made up to a specific gravity of 1.1000, but where the substance was not sufficiently soluble for this, 10 grams were digested for twenty-four hours with 100 cubic centimeters of distilled water. All the solutions were filtered through washed filters before being used. The ordinary city supply, from a faucet in the laboratory, was used for the determinations made last year, contained in the first part of the table; and such water is usually considered the best for such work, as the water is drawn out of a large body from below the surface. For the later results, however, ordinary distilled water had to be used, but all the water used was taken from the same supply and was siphoned off when needed:

Surface tension of various solutions.

(Gram-meters per square meter.)

Solution of—	Specific gravity.	Number of measurements from which the mean is taken.	Mean.	Highest.	Lowest.
Salt	1.070	6	7.975	8.126	7.796
Kainit	1.053	6	7.900	7.993	7.805
Lime	1.002	4	7.696	7.750	7.674
Water	1.000	18	7.668	7.923	7.506
Acid phosphate	1.005	4	7.656	7.800	7.563
Plaster	1.000	9	7.638	7.730	7.572
Ammonia	0.960	6	6.869	6.950	6.826
Urine	1.026	10	6.615	6.740	6.471

Surface tension of various solutions.

(Gram-meters per square meter.)

Solution of—	Specific gravity.	Surface tension.	Solution of—	Specific gravity.	Surface tension.
Magnesium chloride	1.1000	7.964	Wood ashes	1.0038	7.674
Common salt	1.1000	7.911	Potassium nitrate	1.1000	7.661
Muriate potash	1.1000	7.907	Potassium sulphate	1.0830	7.658
Thomas slag	1.0012	7.890	Ammonium nitrate	1.1000	7.656
Kainit	1.1000	7.889	Dried fish	1.0026	7.594
Marl	1.0013	7.855	**Water**	**1.0000**	**7.532**
Potassium chloride	1.1000	7.853	Stable manure	1.0013	7.464
Ammonium sulphate	1.1000	7.834	Acid phosphate	1.0104	7.414
Dried blood	1.0001	7.764	Cotton-seed meal	1.0054	6.534
Ground bone	1.0007	7.749	Tankage	1.0169	4.844
Sodium nitrate	1.1000	7.730	Cotton seed	1.0070	4.788
Sodium sulphate	1.1000	7.730			

Surface tension of soil extracts.

No.	Soil.	Specific gravity.	Surface tension.
295	Kentucky blue grass	1.000	7.244
281	Triassic red sandstone	1.000	7.244
279	Wheat	1.000	7.098
....	Garden	1.000	7.089

The determination was made by the method of the rise in a capillary tube. A short piece of thermometer tubing was used, the diameter of the bore being determined by careful microscopic measurements with a micrometer eye piece. Sections of the tube, above and below the piece taken, appeared very uniform and so nearly circular as to be within the limit of error of observation. The diameter of the tube was taken at 0.5578 millimeters, and the figure 0.0558 centimeters was used in the calculation of the results. The tube was very thoroughly cleaned after each observation, or set of observations, with a strong caustic potash solution, and, after washing, was allowed to stand for some time in a saturated solution of bicromate of potash in strong sulphuric acid. The height of the rise in the capillary tube was measured with a cathetometer.

The following formula was used for the calculation of the results:

$$T = \frac{h\ d\ \omega}{4\ cos.\ a}$$

Where T is the surface tension; d is the diameter of the tube in centimeters; h the height to which the liquid rises in the capillary tube in centimeters; ω is the specific gravity of the solution; and $4\ cos.\ a$ refers to the angle of the liquid with the side of the glass tube. In regard to this latter, 5° 24′ was taken as the edge angle. This is the mean of 11 determinations given by Quincke of the edge angle of pure water and glass.* In regard to saline solutions, Quincke says, that "according to these researches the edge angle

*Quincke on edge angle and spread of liquid on solid bodies, Phil. Mag., 1878.

appears to increase a little with augmenting concentration of the saline solution, but otherwise, to differ only inconsiderably from the edge angle of pure water."

In regard to the results themselves, most of the salts have increased the surface tension of the water, while the organic matters have generally lowered it. Cotton-seed meal, tankage, and cotton seed have lowered the surface tension very considerably. The determinations of the surface tension of these three substances were not very satisfactory, as the solutions were very viscous and moved very slowly in the capillary tube, continuing to fall for a long time after the tube had been immersed and raised again in position for the reading. The very low result with the cotton seed is probably due to the oil, most of which is expressed in the preparation of the meal.

Cotton seed and cotton-seed meal are both used as fertilizers in large quantities at the South. Opinion seems to be very evenly divided as to which gives the better results; some claiming good results from the one and rather injurious results from the other. It has been argued that as the oil has no fertilizing value its presence can do no good in a fertilizer, but on the contrary may do harm, by preserving the substance from disintegration and solution; and it has been argued that it is not only a profit to the cotton planter to have his seed converted into meal, from the value of the oil obtained, but that the value of the product itself is increased as a fertilizer. There are so many positive statements, however, of the greater value of the seed on certain soils than of cotton-seed meal, that I cannot but think in some soils or under some conditions the oil in the seed must have a beneficial effect, apart from any slight fertilizing value it may have, in its effect on the physical condition of the soil due to this very low surface tension of its extract, and in the effect which it may have on the arrangement of the soil grains through flocculation or the reverse.

It has frequently been observed that an application of magnesium chloride, salt, or muriate of potash tends to keep the soil more moist in dry weather. These substances have the highest surface tension of any in the table. They would tend to increase the surface tension of the soil moisture and increase the power the soil has of drawing water up from below, and it is probably this which explains the action of these salts referred to.

On the other hand, the injudicious use of concentrated organic matters in a dry season may "burn out" the land and make it drier than it would otherwise be, as the organic matter would lower the surface tension of the soil moisture and the soil would have less power of drawing water up from below for the support of crops; although their judicious use in favorable seasons would tend, in another way, to make the soil more retentive of moisture, as will be shown.

The surface tension of several soil extracts are given in the table, and these are seen to be very much lower than that of pure water. The extracts were made by rubbing up 10 grams of the subsoil with just sufficient water to cover it, and this was allowed to digest for twenty-four hours, being frequently stirred. The extracts were, in most cases, turbid, but the matter in suspension was so fine that it could not be removed with a filter.

The contact of the water with the subsoil lowered the surface tension very considerably, but as this extract was still very much more dilute than the ordinary soil moisture the surface tension of the soil moisture itself must be assumed to be considerably lower than the tension of these extracts. It was not considered advisable at this time to extend these investigations further, although there is an opening here for some interesting work.

There is a very interesting application of this low surface tension of soil moisture. It is a matter of very common experience with gardeners that if a plant or piece of lawn is watered in a very dry season, by applying water to the surface of the ground, the watering has to be continued thereafter during all the dry season, as the result of a single watering is to leave the ground drier than it would otherwise have been. They usually put off watering as long as possible for this reason, and when they once begin they continue it. King has proved this experimentally by watering a piece of ground and letting it stand for twenty-four hours. He then found by direct determinations that the upper foot was wetter than immediately before the watering, but that the lower depths of the soil, down to 36 inches deep, were drier than before the watering. It would seem in this case that the higher surface tension of the pure water, or of the more dilute soil moisture in the surface soil, had pulled up water from below, where the surface tension is less, and the danger would be that this water being brought near the surface would then evaporate quickly, and so more of the original soil moisture would be lost by evaporation than if the water had not been applied to the surface.

Several years ago the writer called attention to the interesting fact that the level of the water in the wells in the grounds of the Agricultural Society in Raleigh, N. C., was lowest during the winter months and gradually rose, notwithstanding the spring and summer droughts, reaching its maximum about August. Goff published similar observations on a well at the New York Experiment Station. In the Sand Hill formation at Columbia, S. C., the wells are at their fullest during excessive dry weather, but immediately begin to fall after a soaking rain following a long dry spell. The application of the foregoing principles seems apparent here, that as the soil becomes drier the surface tension of the soil moisture is reduced so that it can not maintain the water at the same height as formerly. The water from the lower depths of the subsoil is, therefore, let down into the well as the surface soil becomes drier and the surface tension of the moisture in the upper layers of the soil is diminished through concentration of the solution. With a soaking rain, the pure water increases the surface tension of the moisture in the upper layers of the soil, and while there is less extent of surface to contract, the greater contracting power more than counterbalances this and water is drawn up from below, or, at least, does not flow so readily into the well.

To sum up, it may be briefly stated that the surface tension, or lifting power of soil moisture, is much lower than that of pure water. Many of the common fertilizing materials increase this surface tension of the soil moisture and increase the power the soil has of drawing water up from below in a dry season, or of drawing water to a a plant to replace that which has been lost by evaporation or has been used up or transpired by the plant. On the other hand, many organic substances lower the surface tension, or pulling power, of water very considerably and lessen the power the soil has of pulling water up from below to supply the loss due to evaporation, or what has been used by plants.

This effect of fertilizing materials in changing the surface tension of a liquid, and thereby changing the force or power which moves water from place to place in the soil, is only a first effect, as the continued use of these fertilizing materials may change the texture of the soil itself and the relation of the soil to the circulation of water.

THE EFFECT OF FERTILIZERS ON THE TEXTURE OF THE SOIL.

Surface tension may be expressed in another way.* The potential of a single water particle is the work which would be required to pull it away from the surrounding water particles and remove it beyond their sphere of attraction. For simplicity, it may be described as the total force of attraction between a single particle and all other particles which surround it. With this definition it will be seen that the potential of a particle on an exposed surface of water is only one-half of the potential in the interior of the mass, as half of the particles which formerly surrounded and attracted it were removed when the other exposed surface of water was separated from it. A particle on an exposed surface of water, being under a low potential, will therefore tend to move toward the center of the mass where the potential, *i. e.*, the total attraction, is greater, and the surface will tend to contract so as to leave the fewest possible number of particles on the surface.

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*This treatment of the subject was suggested by an article by Lord Rayleigh in the Phil. Mag., Nov. and Dec., 1890; and I am further indebted to Dr. Arthur L. Kimball, formerly of the Johns Hopkins University, but now of Amherst, Mass., for much valuable advice and suggestion in the application of the principles to the phenomenon of flocculation.

If instead of air there is a solid substance in contact with the water, the potential will be greater than on an exposed surface of the liquid, for the much greater number of solid particles will have a greater attraction for the water particles than the air particles had. They may have so great an attraction that the water particle on this surface, separating the solid and liquid, may be under greater potential than prevails in the interior of the liquid mass. Then the surface will tend to expand as much as possible, for the particles in the interior of the mass of liquid will try to get out on to the surface. This is the reverse of surface tension. It is surface pressure, which may exist on a surface separating a solid and liquid.

This probably explains the phenomenon of flocculation, a phenomenon of very great importance in agriculture.

Muddy water may remain turbid for an indefinite time. If a trace of lime or salt be added to the water the grains of clay *flocculate*, that is, they come together in loose, light flocks, like curdled milk, and settle quickly to the bottom, leaving the liquid above them clear. Ammonia and some other substances tend to prevent this and to keep the grains apart, or to push them apart if flocculation has already taken place. This is similar to the precipitation of some solid matters from solution. When lime is added to a filtered solution of an extract of stable manure, the organic matter is precipitated in similar loose, bulky masses. This matter of potential would seem to have a bearing on all cases of precipitation, as the phenomena of flocculation and precipitation are really quite similar. It would seem to be one of those points between physical and chemical forces which have been sharply marked in the past, but which are now fast disappearing as these two sciences are coming closer together.

If two small grains of clay, suspended in water, come close together they may be attracted to each other or not, according to the potential of the water particles on the surface of the clay. If the potential of the surface particle of water is less than the particle in the interior of the mass of liquid, there will be surface tension, and the two grains will come together and be held with some force, as their close contact will diminish the number of surface particles in the liquid. If, on the other hand, the potential of the particle on the surface of the liquid is greater than of the particle in the interior of the mass, the water surface around the grains will tend to enlarge, as there will be greater attraction for the water particles there than in the interior of the mass of liquid, and the grains of clay will not come close together and will even be held apart, as their close contact would diminish the number of surface particles in the liquid around them.

This hypothesis would seem to be easy to prove experimentally, and it was hoped that this could be done in time for this report, but there has not been time, although the apparatus has been ready for some months.

Much interesting work has been done by Hilgard, Brewer, and Carl Barus on this matter of flocculation. They all assume a chemical hydration of the fine particles of clay as an important factor in the suspension of the clay in water, and of de-hydration by salt or lime, in the flocculation of a turbid liquid. While such hydration and de-hydration may occur, it does not seem at all necessary for the continued suspension and almost indefinite suspension under ordinary conditions of fine clay particles in a turbid liquid. I can not agree with Brewer that clay particles are ultra-microscopic, although they are exceedingly small and very difficult to define. In a turbid liquid which has stood for several weeks and is only faintly opalescent, a drop of the liquid carefully evaporated on a cover glass, ignited and stained, as in ordinary bacteriological examinations, will show particles under an oil emersion objective, not very sharply defined to be sure, under such a high power, but still of measurable size, ranging from about $\frac{1}{10}$ of a space of my eye-piece micrometer to about $\frac{1}{2}$ of a space. The lower limit would give a value of .0001 millimeter and as this has been verified a number of times in turbid liquids which have stood so long as to be only faintly opalescent, I have assigned this as the lowest limit of my "clay" group, pending further and more exact determinations in which a turbid liquid shall be examined at frequent intervals during subsidence, and where precautions have been taken to destroy and exclude bacteria.

Fine dust and ashes, and even filings of metals, remain in suspension in the air for days and even months in very apparent clouds or haze, although they may be a thousand times heavier than the surrounding air. Particles of clay, no smaller than the limits which have been assigned, should remain in suspension in the much heavier fluid water for an indefinite time, for the volume or weight of a sphere decreases so much more rapidly in proportion than the surface, that there is relatively a large amount of surface area in these fine particles and a great deal of surface friction in their movement through a media, and they would settle very slowly. This is clear from the following calculation:

The volume of a sphere $= \frac{4}{3} \pi r^3$

The surface of a sphere $= 4 \pi r^2$

The volume or weight decreases proportionately faster than the surface area. For, consider a sphere of a radius of one inch. The volume will be $\frac{4}{3} \pi 1^3$ and the surface $4 \pi 1^2$. If, now, this sphere be reduced in size until the radius is $\frac{1}{100}$ of an inch, the volume will be $\frac{4}{3} \pi \frac{1}{1000000}$ and the surface of the sphere will be $4 \pi \frac{1}{10000}$.

If we assume now the mean diameter of several of our separations in a mechanical analysis we will have the following values:

Diameter 1.5 millimeters, fine gravel.

Diameter 0.075 millimeters, very fine sand.

Diameter 0.00255 millimeters, clay.

If we assume the volume, or weight, of the gravel to be unity, then for very fine sand—

The volume decreases in the ratio 1 : 0.000125.
The surface decreases in the ratio 1 : 0.2556.

For clay—

The volume decreases in the ratio 1 : 0.000000004853.
The surface decreases in the ratio 1 : 0.000286.

If the lowest value given above is assumed for the diameter of the clay particle (.0001 millimeter) the ratio would be, of course, still more striking. As it is, the relatively large surface area of these fine particles would allow them to subside only with extreme slowness, and it would probably seem that under ordinary conditions, in which the mean daily range of temperature is 20°, the mean monthly range 50°, and the yearly range 100° F., that the ordinary convection currents, induced by this normal change of temperature, would be sufficient of itself to keep these fine particles in suspension in the liquid for an indefinite time, as it is known that currents of air keep fine particles of dust in suspension. It does not seem as though it were necessary to consider the chemical hydration hypothesis to explain the suspension of fine particles in water; nor the de-hydration hypothesis to explain the flocculation of clay, when the grains, under a low potential, can come within the sphere of their mutual attraction and fall or rise together in a loosely united mass.

This matter of flocculation has a most important bearing on the arrangement of the soil grains, and the relation of the soil to water. It will be remembered that there is, on an average, about 50 per cent. by volume, of empty space within the soil. This empty space is divided up by a vast number of grains of sand and clay. If these grains are evenly distributed throughout the soil, so that the separate spaces between the grains are of nearly uniform size, water will move more slowly through the soil than if the grains of clay, through flocculation, adhered closely together and to the larger grains of sand, making some of the spaces larger and others exceedingly small.

The movement of water through capillary tubes is according to the *fourth* power of the radius. If we have ten capillary tubes of equal size, and ten other tubes with the same total area of cross section, but with one of the tubes large and the other nine tubes exceedingly small, water will move much faster through these tubes of uneven size than it will through the others.

We have, then, this principle to work on in the improvement of soils. In a close, tight clay in which water moves slowly, the continued use of lime may cause flocculation; the grains of clay will move closer together, leaving larger spaces for the water to move through. This is undoubtedly the trouble in the clays of the Potomac formation in Maryland, the grains are very evenly distributed and the flow of water is so extremely slow that the soil is practically impervious to water. In such a soil a rapidly growing plant might perish for lack of sufficient water supply, when it was shown by analysis that the soil contained a large amount of water. The movement of water would be so slow that the soil could not supply the plant with water rapidly enough for its need, and the plant would suffer for water as in a light sandy land.

On the other hand, there are soils in which the clay is held so closely to the grains of sand as to give the soil the appearance and properties of a sandy soil, although there is as much clay present as there is in many of the distinctively "clay" lands. This will be shown very clearly in speaking of the Wedgefield, S. C., soils, in another place. We will speak of this matter more at length when we come to speak of the application of these principles to the improvement of soils. Most of our work has been on the determination of the approximate number of grains per gram, to show how much the empty space in the soil has been divided up; and this matter of the determination of the arrangement of the soil grains in their natural position in the field has hardly yet been taken up.

This movement or rearrangement of the soil grains could readily occur in a soil, even if the soil were only slightly moist, for the diameter of the fine silt and clay particles would be much less than the mean thickness of the film of water in the soil, and they could move freely as though they were immersed in a relatively deep fluid. The forces which move them, as will be shown later, are changing moisture content and possibly changing atmospheric pressure, while the condition which determines their close contact will be the surface tension or potential around the soil grains; and this can be changed, as we have seen, by the different fertilizing materials, when the grains will assume a closer or a looser arrangement.

THE VOLUME OF EMPTY SPACE IN SOILS.

There is, on an average, about 50 per cent. by volume of empty space in soils. The amount in the soil proper will vary with the state and stage of cultivation, but the empty space in the undisturbed subsoil will remain fairly constant. The amount of space in the soil may be found by completely filling a short depth of a known volume of soil with water. The weight of the soil before and after the introduction of the water will give the weight of water or the volume of the space. Or the amount of empty space may be found by calculation from the weight of a known volume of soil and the specific gravity. The weight of a known volume of soil in its natural position in the field can be determined as follows: An iron or brass tube, about 2 inches in diameter and 6 or 9 inches long, is driven into the ground to a depth of 6 inches. The tube is then dug out, a knife being passed under the lower edge to cut off the cylinder of soil in the tube. The soil is then carefully removed, dried, and weighed.

From the weight of soil and the volume of the tube, the volume of empty space may be found by the following formula:

$$S_1 = \frac{\left(V - \frac{W}{\omega}\right) \times 100}{V}$$

Where S_1 is the per cent. by volume of empty space, V is the volume of the tube in cubic centimeters, W is the weight of soil in grams, and ω is the specific gravity of the soil.

At first a piece of 2-inch boiler tube was used for taking the samples, one end of the tube being turned off in a lathe to give a good cutting edge. It was found, however, that the friction against the inside of the tube forced the cylinder of soil down a little so that it was feared that the weight of soil would be too light. Such a tube was used in the South Carolina work. In the more recent work a brass tube has been used, which has a clock spring securely soldered in one end, which is turned off in a lathe to give a good cutting edge of hard steel. The area inclosed by this cutting edge has been accurately determined. The tube is 9 inches long, with a mark on the side of the tube 6 inches from the cutting edge, and the tube is driven down into the soil until this mark is even with the surface of the ground. The advantage of this arrangement is that the clock spring cuts out a cylinder of soil of a definite area of cross section and friction is reduced to a minimum, while the soil can be readily removed from the tube. The sampling may be done for every 6 inches down for any desired depth.

The per cent. by volume of empty space varies from about 35 per cent. in the undisturbed subsoil of a coarse, sandy land to 65 or 70 per cent. in the subsoil of a strong clay land.

In "How Crops Feed," Johnson gives the weight of a cubic foot of sandy land at 110 pounds, and a cubic foot of clay soil at 75 pounds. Assuming 2.65 as the specific gravity of the soils, this would give about 34 and 55 per cent. by volume of empty space, respectively, in these soils.

The term "light soil" is thus commonly applied to that which actually weighs a good deal more than what is called a "heavy soil." The terms refer to the texture of the soils and the ease with which they can be worked.

The amount of space has been determined in a number of subsoils in South Carolina, in their natural position in the field, including a wide range of soil formations. The per cent. by volume of empty space is given in the following table:

Empty space in South Carolina subsoils.

(Per cent. by volume.)

78.	Wedgefield (sandy land)	41.80
66.	Gourdins	42.82
57.	Sumter	44.10
80.	Lesesne	46.41
57*a*.	Sumter	47.70
69.	Gourdins (Mr. Roper)	49.74
64.	Lanes	50.00
74.	Wedgefield ("Red Hill" formation)	50.03
69*a*.	Gourdins	50.25
53.	Charlotte, N. C	52.05
71.	Gourdins ("bluff land")	55.40
53*a*.	Charlotte, N. C	57.19
76.	Wedgefield ("gummy land")	58.46
76*a*.	Wedgefield ("gummy land")	61.54
42.	Chester ("pipe clay")	65.12

The amount of empty space has been determined in only a few of the Maryland soils, with the following results:

Empty space in Maryland subsoils.

(Per cent. by volume.)

246.	Truck land, Tick Neck	37.29
246.	Truck land, Shipley	39.00
563.	Truck land, Armiger	41.25
478.	Wheat and late truck, Shipley	42.72
567.	Truck land, one mile west of Armiger	43.90
579.	Truck land, Rock Point	45.54
592.	Barren Potomac clays	47.19
599.	Wheat land, South River	51.48

As opportunity offers, these determinations will be made in other parts of the state, especially in the heavier soils of western Maryland.

The following values have been used in all of our work, the specific gravity in all cases being taken as 2.65:

Per cent. by volume of space.	Weight of unit volumes of soil.		Per cent. by weight of water. Saturation.
	1 cc. grams.	1 cu. ft. grams.	
40	1.5900	45.020	20.10
45	1.4575	41.260	22.41
50	1.3250	37.510	27.42
55	1.1925	33.750	31.55
60	1.0600	30.044	36.14
65	0.9175	26.334	41.22

A soil having 40 per cent. by volume of empty space will hold 20.10 per cent. by weight of water when all the space within the soil is filled. A soil having 55 per cent. by volume of empty space will hold 31.55 per cent. by weight of water when all the space within the soil is completely filled.

This amount of empty space in the soil is an important factor in the movement of water through the soil and in the drainage of land.

It will be seen that when the soils are saturated the sandy land has a capacity of only about two-thirds or one-half the amount of water which the clay soils can hold. When these soils are saturated the water may move off through the clay soil more easily and more rapidly, notwithstanding the smaller size of the separate spaces, because the clay soil will hold more water than the sandy land. Where the soils are short of saturation these conditions are reversed, as the size of the separate spaces very largely determines the rate of flow, and the spaces within the sandy land being larger water flows through more readily.

The size of the grains has an important value in determining the amount of empty space within the soil. Most of our soils are of sedimentary origin, or are derived from rocks which are themselves of sedimentary formation. The material out of which the soils are formed has been deposited from suspension in water. The larger the size of the grains the closer the arrangement will be, so that in a coarse sandy soil there will be less empty space than in a fine clay. If cannon balls were poured into a measure and allowed to settle under water they would take up a very close arrangement, because their volume or weight is large in proportion to their surface area, and their weight is sufficient to overcome the resistance of the water and the resistance offered by the adjacent balls. If fine road dust be poured into a similar measure and allowed to settle under water, the volume or weight of the grains is so small in proportion to the surface area that there will be relatively a great amount of friction as the particles descend, so the descent will be extremely slow. Then as the particles touch, the weight of each is not sufficient to overcome the friction against the sides of the adjacent particles and they do not settle into the same compact and close arrangement as the heavier cannon balls, but take up a looser and a lighter arrangement, leaving more empty space. To compact a quantity of this material into a space occupied by an equal weight of the cannon balls would require a very considerable pressure to overcome the resistance offered by the friction between the surfaces of the adjacent grains.

This will account for the large amount of space in clay soils of sedimentary origin, or in clay soils derived from the disintegration of sedimentary rocks; but it is an interesting fact that these same relations hold with soils derived from crystalline rocks. It can hardly be supposed that just 40 per cent. of all such rocks as produce sandy soils have been dissolved out in one case, while 55 or 60 per cent. have been dissolved and leached out of other rocks which give clay soils on disintegration.

It seems much more probable that on disintegration the grains are pushed apart and the volume of material is increased. It must be remembered that in the case of clay soils there is an immense amount of surface area in proportion to the amount of material, and that any forces that would tend to push the grains apart would have, relatively, great effect. It is very easy to show that there are forces within the soil that would tend to push the grains apart, as is shown in the swelling of clay when wet. It is probable that the tension or potential on the surface separating the soil and water will largely determine how close the grains may come, as in the phenomenon of flocculation already described. If the grains are closer than a certain distance apart there will be this tendency for them to move further apart. It will also be shown in another place that the soil grains are very constantly moving back and forth through the influence of changing climatic conditions, changing water content, and, probably, with changing chemical composition of the soil moisture. It will probably be found that in the disintegration of rocks the fine material swells and occupies a larger volume than before. The finer the material the more surface there is for the forces to act against to keep the grains further apart, and the greater the resistance against their taking up a closer arrangement.

Another property of clay may be mentioned here, due to this function of the small size of the grains. In a symmetrical arrangement of the grains in a soil containing 47.64 per cent. by volume of empty space, each grain will touch the surface of six adjacent grains. There is a certain amount of surface attraction between these particles.

If the grains are large they still only touch at six points, and the weight of the grains is sufficient to overcome this slight surface attraction. A lump of wet sand will fall apart as it dries, for it is bound together by the contracting power of the film of water which surrounds it, and when this is removed by evaporation the weight of the grains is sufficient to overcome the surface attraction of the relatively large and heavy particles, and they fall apart.

If the grains are very small, like grains of clay, the surface attraction of the grains is sufficient to bind the mass into a compact lump when dry; for while there are still only six points of contact for any one grain, there are many more grains and so many more points of contact in a given weight of material. If the size of the grains was still further reduced to molecular proportions the mass would assume the hardness and rigidity of a single grain of sand or clay.

When a dry, compact mass of clay is wet with water the water forces itself in between the grains and forces the grains themselves apart, and the clay swells; but as the grains are held together by their own surface attraction, which is relatively very much greater than with the grains of sand, as well as by the contracting power of the film of water which surrounds them, and as the water keeps them from actual contact and free to move or slide over one another, the mass assumes a plastic condition characteristic of clay when wet. It would seem that most of the peculiar functions of clay may be explained by purely physical laws, and that they are very largely due to the one function of the small size of the grains. It is probable, therefore, that if quartz could be powdered so fine that the diameter of the grains would come within .005–.0001 millimeter, they would have all the characteristic properties of clay, forming a plastic mass when wet and a hard, compact lump when this wet mass was dried. It would probably absorb water quite as readily as clay does, for it must be understood that this peculiar absorptive property of clay is due to the relatively large extent of surface area and to the extremely small size of the capillary spaces between the grains, and not to any inherent "stickiness" or absorptive power of the grains of clay, which are claimed by some to be porous and to "suck up water as a sponge." The slight film of moisture on the surface of a small watch glass is difficult to get rid of, and is sufficient in quantity to vitiate a careful analysis unless it is always driven off before the glass is weighed. This glass has hardly more than 2 or 3 square centimeters of surface per gram, but if this gram of glass were ground up as fine as the heavy clay of a limestone formation, it may have as much as 5,000 square centimeters of surface area per gram, and each unit of surface may attract as much moisture as before, so that the amount of moisture which the soil can hold when air-dry may amount to several per cent. of the weight of soil.

THE RELATION OF GEOLOGY TO AGRICULTURE.

There are a number of well-marked types of soil in Maryland, some suited to grass and wheat, others to wheat but rather light for grass, others to tobacco, truck, or left out as barren wastes. The texture and general appearance of these soils differ very much, so that one can tell at a glance to what kind of crop each of these types is best adapted. It will be shown that from this difference in texture, which is so very apparent to the eye, there is a marked difference in the relative rate with which water moves within the soil, and the ease with which the proper amount of water may be maintained and supplied to the crop.

As crops differ in the amount of water which they require, and in the amount of moisture in the soil in which they can best develop, this difference in the relation of these soil types to water probably accounts for the local distribution of plants.

In greenhouse culture the same kind of soil is used for all kinds of plants, but great judgment is required in watering the plants. Some plants require a very wet soil, others must be kept quite dry. The amount of water required will not be the same at different stages of development of the plant. During the earlier growing period the soil is kept quite wet, but during the fruiting or flowering period the soil is kept much drier. Each class of plants requires, in this way special treatment, and it is through this judicious control of the water supply in the soil and the temperature of the air that the best development of each class of plants is attained.

Our soil types, therefore, in having different relations to the circulation of water, partake somewhat of these artificial conditions in greenhouse culture, and on each of them certain classes of plants will find conditions of moisture best suited to their growth and development.

Our soils have been formed from the disintegration, or decay, of rocks. The rocks are made up of different minerals, the most common of which are quartz, feldspar, and mica. The kind of rock is determined by the kind and relative amount of each of these minerals of which it is made. When the rocks decay, part of the minerals, or the cementing material, is dissolved and carried off, and many of the minerals themselves are changed. Now the texture or the relative amount of sand and clay contained in the soil resulting from the disintegration of these rocks, *in situ*, will depend upon the kind of rock, that is, upon the minerals of which it was composed.

The soils of northern-central Maryland have been formed from the disintegration, *in situ*, of the crystalline and semi-crystalline rocks of the Piedmont Plateau.

The material resulting from the disintegration of these rocks is slowly washed away and carried off by streams and rivers. As the current of water becomes slower near the sea the sand is deposited along a rather narrow shore line, while the finer particles of clay are carried further and deposited over wider areas. The conditions where some parts of this material are being deposited may be favorable to the growth of coral and of various kinds of shellfish, so that their remains accumulate in beds of great thickness, giving the material for the limestone of the present day. These sediments are thus assorted out by subsidence in water of different velocities, as though they had been sifted and the different grades of material spread out over wide areas. The soils of southern Maryland and the Eastern Shore are of this unconsolidated sedimentary material, which is still in the first stages of rock formation.

In former geological periods similar sediments, having been slowly deposited in beds of great thickness, were converted into rocks, forming sandstones, limestones, and shales; the sandstone, where the coarser material has been deposited near the shore; the limestone, where the shells have accumulated; and the shales, where the fine mud has been spread out over a wide area of still water.

It is from the disintegration of these "sedimentary" rocks, which have since been raised above the surface of the water and folded into a succession of mountain ranges, that the soils of western Maryland have been formed. There are the limestone valleys, where shellfish were once abundant, and where now is a strong clay soil well adapted to wheat, composed of what was once the impurities of the limestone rock, which has been left as the more soluble lime has been dissolved and carried away; the sandstone ridges, some of which, resisting decay, form the mountain ranges, while others, made of finer grains of sand and less firmly cemented together, form some of the fertile hill and valley lands; the shales, in which the grains of mud were so extremely small that they have not thoroughly disintegrated in this State, and the soil is filled with fragments of the rock and supports but a scanty mountain pasture.

Geology defines the limits and areas of these different formations and of these different rocks, and as I have shown that these rocks determine the texture of the soil, a thorough and detailed geological map of the state should answer for a soil map. Any one familiar with the texture of the soil, or kind of soil, formed by the disintegration of granite, gabbro, and the different kinds of limestones, sandstones, and shales, should be able to tell by a glance at the map the position and area of each kind of soil. Each color on the map would represent a soil formation which under prevailing climatic conditions would be best adapted to a certain crop.

The wheat, tobacco, truck, and barren lands of southern Maryland are each confined to certain different geological formations for their best development, and a geological map of this portion of the state should show the area and distribution of the lands best adapted to these crops.

There is usually some marked and distinctive botanical character in the herbage of these different soil formations. We have pine barrens, white oak lands, black jack lands, chinquapin lands, grass lands, wheat lands, and truck lands. These names convey a very good impression of the character and texture of the soil, and they should be more generally used. When a soil formation is spoken of as black jack land, the name conveys a distinct impression of the kind of soil, for a soil must have a certain characteristic texture to produce such growth.

SOIL TYPES.

The soils of any wide locality, especially in our Eastern States, appear, at first sight, to offer an endless field of research in the great variety often seen on a single farm and in the same field; but a more comprehensive view of the matter will show this to be due to local causes, which have mixed up and modified the original soil formation. These local modifications may be neglected for the present, until the general features of the representative soils of the region have been worked out. The characteristic properties of great soil formations, or soil types, must first be determined, and then more detailed work may be done in examining soils of local interest.

Why will not truck, tobacco, wheat, and grass grow equally well on all soils? What are the characteristic properties of a good wheat land, of the best tobacco soil, of the best grass land, of the best land for market truck? What is it in the appearance of the soil which enables a farmer to place it in one or the other of these classes? It is not until this problem has been mastered and these very evident differences in the soils have been explained, that the real and full value and application of the chemical determination in plants and soils will be seen. As a rule, the chemical analysis of a soil will not enable a farmer to determine to what his farm is best adapted; but, on the contrary, the farmer, from his experience and judgment, must inform the chemist of this point, and must tell him of the strength and condition of the land.

A large number of samples of soils and subsoils, of representative agricultural value and importance, have been collected in Maryland, and these samples have been classified according to their agricultural value and their geological origin. The soils of all the principal agricultural regions of the state can thus be classified under not more than fifteen different types, and a number of these do not differ materially in their agricultural value, but are given a separate place on account of the distinctive geological formations. The different types will be described when we come to speak of the mechanical analysis of the soils.

THE INTERPRETATION OF THE MECHANICAL ANALYSIS OF SOILS.

THE METHOD.

The method which has been employed for the mechanical analysis of soils is substantially Johnson and Osborn's "beaker method." Twenty grams of the air-dry material were rubbed up in a mortar, with successive quantities of water, and a few drops of ammonia to prevent flocculation, until the liquid on standing a moment became quite clear and the soil remaining in the mortar contained no grains smaller than .05 millimeter, as shown by microscopic measurements. A rubber pestle was used so that the soil grains should not be broken. A very good pestle can be made by putting a rubber cap, such as is used on the ends of chair legs or crutches, over the handle of a porcelain pestle. The coarse material in the mortar was then dried and sifted through a series of sieves with round holes, 2, 1, and .5 millimeters in diameter, and through two pieces of bolting cloth with square holes, having an aperture, respectively, of very nearly .25 and .1 millimeter, the holes being very uniform in size, as shown in the microscopic measurements. The turbid liquid, which was poured off from this coarse material, was allowed to settle until all grains larger than .05 millimeter had settled. The turbid liquid was then poured off and the material in the bottom of the beaker was stirred up with a fresh quantity of water, and material larger than .05 millimeter was allowed to settle as before. This was repeated until all material finer than .05 millimeter had been removed. The remaining coarse material was thrown in with the "very fine sand." Other separations were made in the turbid liquid, until all grains larger than .005 millimeter were removed, and everything smaller than this was included in the clay group. The turbid liquid containing the last separation was carefully measured in a liter flask, and 100 cubic centimeters of this turbid liquid out of every liter was evaporated to dryness in a porcelain dish. The finest separations, including the silt, fine silt, and clay, were all ignited and cooled in a desiccator before weighing. The coarser grades of sand were not ignited as the amount of moisture which the air-dry material contained was found to be extremely small and within the limit of error of such an analysis. .0001 millimeter is taken as the smallest limit of the clay group, because it is believed that practically all the clay particles are larger than this.

There are, relatively, very wide limits in this clay group, as the largest diameter is fifty times larger than the smallest. This is of very great importance, as the extremely small size of the grains gives a very large number of grains for a given weight of material, and the aggregate extent of surface area of this vast number of particles is usually larger than of all the other grades combined. It would be very desirable to have a greater number of separations, an infinite number if this were possible, so as to have very narrow limits between the diameters and so that the diameters of all the particles in a single separation shall be very nearly of the same size. It is practically impossible, however, with this beaker method to make more than the number of separations which have been adopted, as it takes a long while to make the separations. This clay group is of so much importance, therefore, that a very slight difference in the value of the diameters will give widely different absolute values in the determination. It is impossible, however, to expect that the absolute number of grains in one gram of soil could ever be determined, and if they could be, the science of mathematics is not refined enough to deal with them as we wish. Comparative results can alone be expected, and one of the essential things in this is to have the mechanical analysis made by methods which give fairly uniform results, while the number and value of the separations, and especially of this clay group, be always the same.

In the mechanical analysis, when any of the separations were allowed to remain some time to settle out, the material in the bottom of the beaker was rubbed up in the mortar with a rubber pestle, as it was liable to cake on standing.

APPROXIMATE NUMBER OF GRAINS IN ONE GRAM OF SOIL.

Having determined the amount of empty space in the soil by a method already given, it is important to know how much this space has been subdivided. There is about half a cubic foot of empty space in a cubic foot of soil, and it is evident that if this space formed one large cylinder a large body of water would flow through with great rapidity. It is also evident that water will flow through this space more and more slowly the more it is subdivided. The amount of subdivision of the space will depend upon the number of grains in the soil, and somewhat upon their arrangement. The approximate number of grains per gram can be calculated from the mechanical analysis of the soil by the following formula:

$$\frac{a}{\frac{\pi (d)^3 \omega}{6}} \div A$$

Where a is the weight of each group of particles, d, the mean diameter of the particles in the several groups, A is the total weight of soil, and ω is the specific gravity of the soil.

In using the formula the per cents are used as grams, thus, if there were 20 per cent. of silt this would be taken as 20 grams, and if the results of the analysis added up 97 per cent. the whole weight of soil would be taken as 97 grams. The diameter (d) is taken as the mean of the extreme diameters given for any group. For instance, for the silt this would be .03, which is assumed to be the diameter of the average sized particle.

The specific gravity has been taken as 2.65 in all the determinations which have been made. This value was originally selected from a statement by Johnson, in "How Crops Feed," page 159, of some determinations by Schöne, and our own results have shown no very good reason for changing this unless the value 2.70 be substituted, or unless the specific gravity of each soil be specially determined for insertion in the formula, which hardly seems necessary at the present stage of the investigation.

The following table gives the specific gravity of some of our type subsoils, the type sample being made up in most cases of samples from a number of localities:

Specific gravity of type subsoils.

No.	Soil.	Air-dry.	Ignited.
276	Pine barrens	2.6388	2.6485
284	Truck	2.6259	2.7016
286	Tobacco	2.6151	2.7100
290	Oriskany	2.6550	2.6583
280	Wheat	2.5949	2.7109
278	River terrace	2.6229	2.6855
181	Triassic red sandstone	2.7115	2.7759
238	Catskill	2.6875	2.7201
289	Shales	2.6625	2.7302
288	Helderberg limestone	2.6978	2.7385
	Average	2.6512	2.7079

Specific gravity of separations.

Diameter.	Conventional names.	Specific gravity.
mm.		
2-1	Gravel	2.6469
1-.5	Coarse sand	2.6547
.5-.25	Medium sand	2.6476
.25-.1	Fine sand	2.6594
.1-.05	Very fine sand	2.6807
.05-.01	Silt	2.7337
.01-.005	Fine silt	2.6642
.005-.0001	Clay	2.8368

The specific gravity of the silt and clay groups in the list of separations is quite high, and the duplicate results, of which the mean is given, were rather wide, for what reason has not yet been determined, unless it is due to chemical changes of the iron compounds in the ignition of the material.

It must be remembered that the results obtained by the use of this formula of the number of grains per gram have only approximate values, and can only be used in comparative work.

The approximate number of grains per gram will be given with the results of the mechanical analysis of the soils. One table will be given in detail, showing the approximate number of grains in each separation in one gram of subsoil, from which it will be seen that the extremely small diameter assigned to the clay group has an important value, as the vast number of grains in this and in the fine silt practically determines the number of grains per gram.

THE ESTIMATION OF SURFACE AREA OF SOIL PARTICLES.

The approximate extent of surface area of the soil grains in one gram of soil can be calculated from the foregoing by the following formula:

$$\pi (d)^2 n$$

in which d is the mean of the diameters of any group in centimeters, and n is the number of particles in the group.

The following logarithmic constants have been used in the calculation of the results, using 2.65 in all cases as the specific gravity of the soil:

Diameter. (d)	Approximate number of grains. (log.) $\frac{\pi (d)^3 w}{6}$	Surface area. log. $(d)^2 \pi$
cm.		
·15	3·6703	2·8493
·075	$\bar{4}$·7674	$\bar{2}$·2473
·0375	$\bar{5}$·8641	3·6451
·0175	$\bar{6}$·8711	$\bar{4}$·9831
·0075	$\bar{7}$·7674	4·2473
·003	$\bar{8}$·5734	$\bar{5}$·4513
·00075	$\overline{10}$·7674	$\bar{6}$·2473
·000255	$\overline{11}$·3616	$\bar{7}$·3101

CALCULATION OF THE RELATIVE RATE OF MOVEMENT OF WATER THROUGH SOILS.

It has been stated that the relative rate of movement of water through soils will depend upon how much space there is in the soil; upon how much this space is subdivided, *i. e.*, upon how many grains of sand and clay there are in the soil; upon how these grains are arranged, and upon how this skeleton structure is filled in and modified by organic matter.

It will be assumed for the present that the grains have the same mean arrangement in all the soils and the influence of the organic matter will be assumed to have the same value in all cases, and this will also be neglected for the present. Where the rate calculated from the mechanical analysis of the soil differs from the observed rate determined experimentally, it may be assumed that the grains have a different mean arrangement in the two soils or that the influence of the organic matter is not the same.

There will evidently be one space, or opening, into the soil for every surface grain, and the approximate number of grains, or of openings, on a unit area of surface may be found by the following formula:

$$N = \left(\sqrt{\frac{M \times W}{V}}\right)^{\frac{2}{3}}$$

Where N is the number of grains, or openings, on one square centimeter of surface, M is the approximate number of grains in one gram of soil, W is the weight of soil, V is the total volume of the soil grains and the empty space.

If the grains are assumed to be symmetrically arranged and the spaces between them cylindrical in form, the radii of the spaces can be found by the following formula:

$$r=\sqrt{\frac{V_1}{\pi N L}}$$

Where r is the radius of a single space, V_1 is the total volume of the empty space, N is the number of grains or spaces on one square centimeter of surface, and L is the depth of the soil.

If the space within the soil is completely filled with water the relative rate of flow of water through the soil will be according to the fourth power of the radius of a single space multiplied by the number of spaces on the unit area of surface, as shown by the following formula:

$$T_1=\frac{N\,(r)^4\,T}{N_1\,(r_1)^4}$$

Where $N-N_1$ are the number of spaces, and $r-r_1$ are the radii of single spaces in the respective soils, and $T-T_1$ the time required for a unit volume of water to flow through the soils under the same head or pressure.

The space within the soil is rarely filled with water in agricultural lands, but the most favorable amount of water for the soil to hold, as Hellriegel and others have shown, is from 30 to 50 per cent. of the total amount of water the soil could hold if all the space within it were filled.

If the space within the soil is only partly filled with water, as in most arable lands, the water will move in a thin film surrounding the soil grains and according to the fourth power of the thickness of the film. The mean thickness of the film surrounding the soil grains may be theoretically determined by the following formula, which is based on the conception that the film is cylindrical and of uniform size throughout:

$$t=r\left(1-\sqrt{\frac{s}{s+p}}\right)$$

Where s is the per cent. by weight of water which the soil will hold when the empty space is filled with water, p the per cent. of water actually contained in the soil, r the radius of a single space, and t the mean thickness of the film surrounding the soil grains.

The relative rate of flow of water through the soils will then be according to the following formula:

$$T_1=\frac{N\,(t)^4\,T}{N_1\,(t_1)^4}$$

It must be remembered that these formulæ give only approximate and comparative values for comparing one soil with another. The structure of the soil is altogether too intricate to expect ever to obtain absolute values.

DETERMINATION OF THE ACTUAL RATE OF FLOW OF WATER THROUGH SOILS.

A method has been given, based on theoretical considerations, for the calculation of the relative rate of movement of water through soils from the mechanical analysis. The following method has been used to determine the actual rate of flow of water through the soil in its natural position in the field, and described in the Experiment Station Record, volume 3, No. 10 (May, 1892), page 68.

To determine the actual rate of circulation of water in the soil or subsoil in its natural position in the field, a hole should be dug, and the soil and subsoil on one side removed to the depth at which the observations are to be made. A column of the soil or subsoil, 2 inches or more square, and 4 or 5 inches deep, is then to be carved out, and a glass or metal frame, a little larger than this and 3 or 4 inches deep, is slipped over the column, and melted paraffine is then run in to fill up the space between the soil and the frame. The soil is then struck off even with the top and bottom of the frame, a piece of linen tied over the under side, or what is better, the frame can rest on some coarse sand or gravel, contained in a funnel, to prevent the soil from falling out and to provide good drainage for the water to pass through. A section of the frame can then be placed on the top and secured by a wide rubber band, or otherwise, and the time noted which is required for a quantity of water to pass through the saturated soil. The initial depth of water over the soil must be the same in all the experiments. Root-holes and worm-holes are to be avoided, and these are particularly troublesome in clay lands. The amount of space should be determined in this or in another sample, as described in a previous section.

These determinations are usually made out in the field. They are rather troublesome to make, especially as most of them have to be made in different parts of the state, and they require considerable time; only a few of these determinations have been made in the soils of Maryland as most of our time has necessarily been occupied in the preliminary work of securing samples from as many widely separated localities as possible, and making the mechanical analysis of the same to give material and data to work on. With this in hand the field has all to be gone over again, to study the texture of the soil and the arrangement of the soil grains, and this will involve the determination of the actual rate of flow of water through the soils in their natural position in the field. The preliminary work had to be done first so that this work would have a meaning. The actual determinations which have been made will be given with the mechanical analysis of the soils.

Considerable work has been done on the flow of water through air-dried soils, loaded into tubes. Eight-inch Argand lamp chimneys are used, with a piece of muslin tied tightly over one end. A mark is placed on the side of the tube 6 inches above the lower end. The chimneys are about 2 inches in diameter, and the capacity of the tube up to the 6-inch mark is about 300 cubic centimeters. The tube is filled with 6 inches in depth of soil by gently tapping the bottom of the tube. The tube is weighed before and after the soil is introduced, when the weight and volume of the soil and the volume of the empty space may easily be calculated if the specific gravity of the soil is known. 2.65 has, in all cases, been used as the specific gravity of the soil. From this data and the mechanical analysis of the soil the relative rate with which water will move through the soil can be calculated.

The soil should then be saturated with water and the tube supported so that the muslin just touches the surface of the water, contained in a vessel below, to reduce any tension at the bottom of the soil. What is better than this is to remove the muslin from the bottom of the tube before the soil is saturated, and place the tube on some fine gravel or coarse sand, contained in a funnel, to keep the soil from falling out, but to provide good drainage for the water. When the soil is saturated and water is flowing from the funnel, an inch in depth of water (41 cubic centimeters) is then carefully poured on the soil and the time noted that is required for it to pass through the soil, or to displace an equal quantity of water from the tube. The initial depth of water in these determinations is 1½ inches, and the time is noted which is required for the water to fall one inch, or to within ½ an inch of the surface of the soil.

It is extremely difficult to fill these tubes in this way with air-dry soil without a separation of the finer particles into separate layers, which would retard the flow of water. The tubes often have to be filled several times before they are uniform in appearance. In view of this difficulty, it is much better to slightly moisten the soil before filling into the tube. But as the amount of moisture affects the arrangement of the grains and the rate of flow, we have used 3 per cent. of moisture in all cases. To mix this uniformly and easily with the soil, rather more than the requisite quantity is poured on to the soil and covered over with the dry material and let stand for a number of hours to soak in. After this it can be thoroughly and easily mixed by hand without the formation of lumps. After thorough mixing it is allowed to stand, if necessary, until the soil contains only 3 per cent. of water, and it is then thoroughly mixed again and loaded into the tube.

This method is not so reliable as where the soil is taken in its natural position in the field, for the effect of drying and the necessary preparation of breaking down the lumps which have been formed in drying, before loading into the tube, may very materially modify the arrangement of the soil grains. Still, when it is remembered, that in plowing the soil is turned over and allowed to fall back as it would fall into the tube and is often quite completely dried out during this process, and that this does not very materially change the arrangement of the soil grains if done intelligently, perhaps these objections are not as serious as they would appear at first sight, and that soil samples brought from a distance can be compared in this way. It would be very desirable if a method could be devised for determining the actual rate of flow of water through soils short of saturation, when they contained, say, 8 or 10 per cent. of moisture.

There is another difficulty encountered in this method, that where the saturated soils are left standing the rate of flow becomes slower and slower, probably caused by a rearrangement of the soil grains, due to the repeated quantities of water changing the composition of the soil moisture. For this reason it is better to pass air through the soil than the denser fluid water. A known quantity of air can be passed through the soil at a definite pressure and the time noted, as in the case of water. This is a much more satisfactory method, as there are no chemical or physical changes to be feared.

THE RELATION OF SOILS TO WATER.

The samples which are to be described have all been very carefully collected by the writer. The early sampling was done with a spade, but most of the Maryland soils have been collected with a 2-inch wood auger, one end being fitted for a small iron pipe which could be inserted at will for a handle. The auger can readily sample to a depth of 18 inches from the surface, and besides the much greater convenience in carrying and in sampling over the spade, it brings up a complete sample to the desired depth, the whole of which is carried to the laboratory, and it is not necessary to mix it in the field to select a small sub-sample, as must be done when the spade is used.

The sample of soil is taken down to the change of color, or, when this is not apparent, to a depth of 6 inches, and the subsoil is taken from below this to a depth dependent upon the nature of the material, but usually to a depth of 18 inches from the surface.

The subsoil alone has been analyzed and examined in most cases, for the soil has been subjected to artificial conditions and manuring, which might materially modify the results of the investigation, and besides, the undisturbed subsoil practically determines the movement of water, and it is the subsoil, rather than the soil, upon which the practical farmer bases his judgment of the strength and character of the land.

The samples have been taken from as widely different localities as possible, and from many different soil formations, and they are accompanied, as far as possible, with very full notes on their geological origin, their agricultural value and importance, and to a lesser degree upon the botanical character of the natural growth. Some of these samples have been quite fully described in the Fourth Annual Report of the Maryland Agricultural Experiment Station, but only such peculiarities will be mentioned here as may seem necessary or desirable in the presentation of the results.

SOUTH CAROLINA SOILS.

Some very interesting conditions were presented in the study of the South Carolina soils, which throw light on the subject under consideration, and which show very plainly the relation of the texture and of the physical properties and condition of the soil to the local distribution of crops.

The conditions most favorable to the production of cotton may be briefly stated as follows: From the time of planting, the temperature and rainfall gradually increase until about the middle of July or the first of August, when the plant has practically attained its growth and has laid up all the food material needed for a full crop. During this growing period an even temperature is desired, with a high temperature as the plant attains good size. Plenty of sunshine is needed, and frequent rather than long continued showers. The ground is thoroughly cultivated and the crop is kept free of weeds and grass to conserve the moisture in the soil. The conditions which prevail are nearly tropical, and if they continued the plant would continue to grow as a perennial shrub with little tendency to ripen fruit. But after the first of August the temperature rapidly falls, there is less rainfall, cultivation is stopped, and the soil becomes cooler and drier, the real growth of the plant is checked, and the food material stored up by the plant is transferred to the fruit, and the plant ripens up a crop.

The *lower pine belt* in South Carolina covers nearly one-third of the state, but produces only about 5 per cent. of the cotton crop of the state. The soils are fair and the meteorological conditions must be favorable, for on one side of this belt are the fertile Sea Island cotton soils along the coast; on the other side is the fertile "red hill" formation, which contains some of the finest upland cotton lands of the state. The land in this lower pine belt is everywhere very level and very low, so that there is poor drainage, the water often rising to within a foot of the surface in the wells, and, indeed, covering much of the country between the water courses, as it can neither flow off the level surface nor down through the already saturated subsoil.

On what are called the "ridge-lands," bordering the water courses, and for two or three miles inland from the principal rivers, which have worn their way down in the soft material for 50 or 100 feet, the soils have good drainage, and very large crops of cotton are produced, while further away from the water courses the land is almost entirely left out in forest growth. Probably much could be done with this land with improved methods of cultivation and by judicious manuring, but the land needs underdrainage, and it would be both difficult and expensive to get good drainage in this low, flat country. Where cotton is cultivated there are all the signs of too moist a soil. The plant attains a large size, and one would suppose it would supply a large yield, but it puts on little fruit, hardly more than a third of what would be expected from the size of the plant, and much of this is lost by rust and shedding. The growth of the plant is not properly checked, and when a change does come it is sudden and severe, and lowers the vitality of the plant, rendering it liable to disease and insect ravages.

The texture of these soils and the relation to moisture undoubtedly determine the low yield of crop. The most important thing which could be done in the improvement of these lands would be the introduction of a system of under-drains, but even without this it would undoubtedly be possible to introduce improved methods of cultivation and manuring which would check this excessive growth, and induce the plant to ripen up a larger crop.

THE SEA ISLAND SOILS.

Very interesting conditions, showing the influence of soil moisture on the local distribution of crops, are seen on the Sea Islands off the coast of South Carolina. The soils of the Sea Islands consist generally of a very fine sand, the particles of which are of very uniform size, as shown by the mechanical analysis. The soils are naturally rather poor but are capable of a high state of cultivation. The natural growth is oak, hickory, gum, and chinquapin. There is no original pine, but fields left out grow up in old field pine. James Island, just across from Charleston, and one of the most northern of the the Sea Islands, and to which these notes have more particular reference, is some 8 or 9 miles long and from 2 to 3 miles broad. The soil on the south side is generally "sandy," with a sandy subsoil down to water level, which is from 5 to 6 feet below the surface. On the north side of the island or that nearest to the mainland, there is a yellow clay or loam subsoil. The surface of the water in the wells is generally 5 or 6 feet below the surface of the ground, and is quite fresh even if the well is near the shore. If the well is much deeper than this, however, the water is salt, even in the center of the island. This is in accordance with a statement made by Storer of conditions prevailing near Boston.

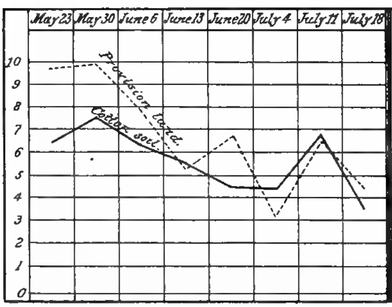
When the Sea Island cotton was first introduced into South Carolina, about 100 years ago, it failed to mature before frost, and for this reason the first crop was lost. The crop ripens now very much earlier so that there is no danger from frost. The planters have evolved a very peculiar system of cultivation, the plants are grown on very high beds or ridges from 12 to 18 inches high, and from 4 to 5 feet broad, partaking somewhat of the nature of the ridges used by the Romans, and for the same reason, *i. e.*, to keep the roots of the plant in thoroughly drained and comparatively dry soil. The subsoil is never disturbed and soft mud from the adjacent marshes and salt marsh grass and litter of all kinds are placed in the bottom of the bed, effectually keeping the roots from developing down into the moist subsoil. The bed itself is very highly manured. During the last twenty years the finest cotton lands have been gradually underdrained with tile drains, costing from $10 to $60 per acre, depending on the character of the land and the distance apart of the tiles. The sandy lands have only to be drained in low places, while in the heavier soils drains are placed from 25 to 100 feet apart and from 2 to 4 feet deep, with a fall of about 5 inches in 100 feet where possible. The planters believe that underdrainage has made the crop much earlier and surer and that the high beds are not now as necessary as formerly. They are able to maintain any grade of cotton desired by judicious cultivation and careful selection of seed.

The finest cotton lands are near the water, where the lands are better drained than in the interior. These lands are given up entirely to Sea Island cotton, and of recent years to early truck and vegetables for northern markets. The land in the interior of the island is not so well drained and does not yield as productive crops of cotton, nor as fine staple, as the crop is generally more liable to shedding, flagging, rust, and insect ravages than on the better drained soils just described; this land is better for corn than the finest cotton soils, and it is generally known as "corn" or "provision land," as it is given up to the cultivation of corn and provisions for the farm.

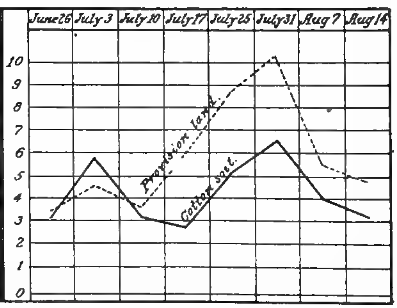
Cotton usually starts out well on this land and the plants attain a large size but put on very little fruit and are liable to disease and insect ravages.

The following diagrams show the moisture curve in two soils from James Island, S. C. Both soils were in cotton and samples of the

James Island, S. C., soils, 1890.



James Island, S. C., soils, 1891.



soil were taken weekly for the moisture determination. The sample was taken with an iron tube 9 inches long and 2 inches in diameter, which was driven down its whole length into the soil. The sample was sent to the station in air-tight glass jars, and the moisture was determined by air-drying about 1,000 grams of the material.

The time covered only a part of the growing period of the crop each year. In 1890 this was of the early part of the season, and in 1891 of the middle and latter part of the true growing season before the ripening period really commenced.

It will be seen that the moisture curve for the provision land is very much more irregular than that for the cotton soil, and it is undoubtedly these marked and sudden changes which render the crop less certain. On July 25, 1891, rust appeared in the cotton on the provision land, and by September 4th the plants had lost nearly all their leaves from this cause.

The planters themselves believe that underdrainage and high beds, with heavy applications of salt mud to keep the roots from developing down into the subsoil, will check the growth of the plant and enable as good crops to be grown here as elsewhere, but as these lands are inland, both the mud and drainage are costly and difficult to apply.

The mechanical analyses of some of the soils from James Island are given in the accompanying table, including three principal types of Sea Island cotton lands and one sample of the "provision" land from the interior, on which cotton cannot be economically produced. The approximate extent of surface area, in square centimeters per gram, and the approximate number of grains per gram, are also given as calculated by the formulæ already given. The results cannot be compared directly with the work on the Maryland soils for there are not so many separations, and the absolute values are not the same.

Mechanical analyses of Sea Island cotton subsoils from James Island, S. C.

Diameter.	Conventional names.	Sea Island cotton lands.			
		82.	84.	86.	88.
		Clay land.	"Sand and gravel."	Sandy land.	Provision land.
mm.					
2–1	Fine gravel	0.00	0.59	0.00	0.00
1–.5	Coarse sand	0.54	3.67	0.00	0.88
.5–.25	Medium sand	1.03	4.27	0.67	2.50
.25–.05	Fine sand*	83.20	78.88	90.14	82.97
.05–.01	Silt	6.44	4.20	3.35	6.30
.01–0	Clay†	7.17	6.63	4.78	5.70
	Total	98.38	98.24	98.94	98.35
Organic matter, water, loss		1.62	1.76	1.06	1.65

Mechanical analyses—Continued.

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
86	Sandy land	4.78	383.7	279,000,000
88	Provision land	5.70	441.9	336,000,000
84	Sand and gravel	6.63	464.8	390,000,000
82	Clay land	7.17	509.7	421,000,000

* Including "very fine sand" of later analyses (.1–.05 millimeter).
† Including "fine silt" of later analyses (.01–.005 millimeter).

The "provision" land need hardly be considered here, for the trouble with the land is admitted to be poor drainage, owing to its location; and in many cases it has a layer of iron ore underlying it at a depth of 3 or 4 feet from the surface.

Of the cotton soils the clay land (82) is considered the strongest soil. With the same treatment it produces a larger yield per acre, although the fiber is rather shorter and heavier, than the sandy land. The Sea Island planters have an admirable method of selecting seed and they can maintain almost any desired grade of lint. They select the sandy land (86), however, in preference to the clay land for the finest grade of lint. With the same seed and treatment the sandy land does not produce so much yield per acre as the heavier clay land; the plants moreover are not so large, the crop ripens earlier, and the lint is somewhat finer and longer. The agricultural value of these cotton soils varies with the amount of clay they contain and with the approximate number of grains per gram, as given in the table, and the planters realize that the sandy soils are less retentive of moisture and are, as a rule, drier, and that it is this fact, rather than lack of plant food, which explains the difference in their agricultural value.

THE WEDGEFIELD SOILS.

Very interesting conditions have also been studied in three soils from Wedgefield, S. C. Wedgefield is situated on a narrow strip of the "red hill" formation, about 2 miles from the Wateree River, and the railroad station is about 150 feet above low water, with a bold bluff coming down to the swamp, about half way between the station and the river. The soil of this red hill formation has a strong, dark red clay-loam subsoil. The formation widens out considerably in Orangeburgh and Aiken counties, and is noted throughout its whole extent for its fertility and the excellent conditions for a good cotton soil. The land is gently undulating, with good surface drainage, and, although a compact red clay from 40 to 80 feet thick, it has good underdrainage. It is considered a very safe soil, as cotton rarely suffers from excessive wet or dry weather and the plants are usually very vigorous and are not subject to rust, shedding, or lice, as on the adjacent lands. With good treatment it may be relied on to produce 1,000 to 1,400 pounds of seed cotton. If anything, the soil is considered rather too close and too retentive of moisture, and this, together with rather high nitrogenous manuring, has inclined the plant on this particular soil to make rather an excessive growth for the amount of fruit which it produces. On the whole, the soil of this formation is considered the finest type of upland cotton soil in the state. The wells are usually about 40 feet deep, but are often 80 feet and even 120 to 160 feet deep.

About 1¾ miles from the station at Wedgefield, there is a range of sand hills bordering the red hill formation and extending for miles up and down the river. The soil and subsoil are coarse, yellow sand, with red clay fully 15 to 20 feet below the surface, on the plateau where these samples were taken just before entering the sand hills proper. Cotton cannot be economically produced on this land, for the soil is so light in texture that the crop suffers in excessive wet or dry weather. With the same treatment it is thought that it will not make one-fifth as much cotton per acre as the "red land." The sandy land makes fairly good crops of corn and is excellent for sweet potatoes, melons, and early truck. It is never planted in cotton by the large planters.

There is a narrow belt, about ½ mile wide at this place, lying between the red hill formation and the sand hills, locally known as "gummy land," because, although it appears to be a coarse, red sand, it gums up and sticks to a plow, especially when it is quite moist. In color it is precisely like the red land, and the mechanical analysis shows that it contains about the same amount of clay. In texture it looks and feels like red sand. In its relation to moisture, also, it behaves more as a sand than as a clay, so that crops suffer in excessive wet or dry seasons. In unfavorable seasons the plants are small and the vitality of the plants is so much lowered that they are rendered liable to disease and insect ravages. In a good season and with the same manuring and treatment it is thought that this land will make only about four-fifths as much crop as the red land, but in unfavorable seasons the difference is much greater than this.

No amount of fertilizers, as usually applied, will make these two soils as productive or as safe for cotton as the red land. The meteorological conditions are the same over all, and the difference is undoubtedly due to the physical properties of the soils, and especially their relation to water, rather than to any difference in chemical composition. The planters themselves freely admit that the peculiarity of these soils and their natural or acquired fertility are largely dependent on their relation to the moisture supply of crops.

The mechanical analyses of these soils are given in the accompanying table, with the approximate number of grains per gram and the approximate extent of surface area of these grains in square centimeters per gram.

Mechanical analyses of subsoils from Wedgefield, S. C.

Diameter.	Conventional names.	74. Red land.	76. "Gummy" land.	78. Sandy land.
mm.				
2–1	Fine gravel	1.11	1.98	2.88
1–.5	Coarse sand	5.92	14.91	31.45
.5–.25	Medium sand	9.67	20.17	27.31
.25–.05	Fine sand*	42.75	25.47	28.14
.05–.01	Silt	7.54	6.92	3.96
.01–0	Clay†	28.85	26.25	3.97
	Total	95.84	95.70	98.68
Organic matter, water, loss		4.16	4.30	1.32

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
78	Sandy land	3.97	284.8	232,700,000
76	Gummy land	26.25	1,358.0	1,587,000,000
74	Red land	28.85	1,496.0	1,736,000,000

* Including "very fine sand" of later analyses (.1–.05 millimeter).
† Including "fine silt" of later analyses (.01–.005 millimeter).

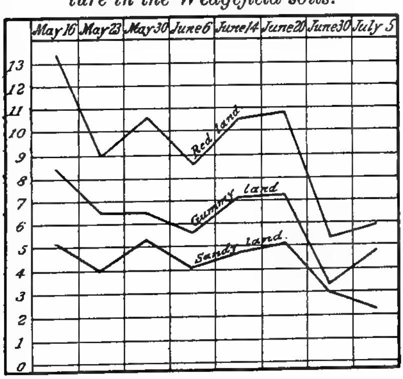
The amount of empty space in these lands is given in a preceding table, and it will be seen from this table that this space is divided more in the red land than in the sandy land, as there are a great many more grains in the former than in the latter. Experiments were tried with the air-dried soils in the laboratory to determine the relation of these soils to water and especially the ease with which water would move through them.

A quantity of the red land was loaded into a tube, the amount of space being determined in the way already described. An inch in depth of water (41 cubic centimeters) passed through the saturated subsoil in 133 minutes. As this soil is considered rather close and retentive of moisture, making the crop rather late in starting off and growing rather late in the fall, a number of fertilizing materials were applied to diminish the rate of flow. A few drops of a saturated solution of gypsum made the water pass in 105 minutes, as a result of several trials.

Taking 133 minutes for the red land as a basis of calculation, the same quantity of water should pass through the same depth of sandy land of a given compactness and as calculated from the mechanical analysis in 5½ minutes. The water actually passed through in 3¾ minutes, a result agreeing very closely with the calculated time. The "gummy land" contains very nearly as much clay and very nearly as many grains per gram as the red land, and it was calculated from the mechanical analysis that the same quantity of water should pass through this subsoil, as loaded in the tube, in 130 minutes. The water actually passed through in 14 and 16 minutes, as a result of several trials. The soil appears like a sandy soil. The mechanical analysis shows that it contains only about the same amount of the different grades of sand as the red land, but it has rather more of the coarser grades. It appears as though the clay were held closely to the grains of sand, through flocculation perhaps, giving the appearance of larger grains than the soil really contains. In the mechanical analysis of the material flocculation was so troublesome that ammonia had to be used to overcome and prevent it, as the clay liquid would settle out clearly and at once without this addition. A few drops of ammonia were, therefore, added to the water as it was passing through the subsoil in the tube, and it checked the rate of flow *at once*, so that it took over 2,000 minutes for the liquid to pass. The alkali was evidently stronger than it should have been, as it made the soil almost impervious to water. The action of the alkali on the soil could be traced as it proceeded down the tube, the soil appearing to slake and the grains of clay to fall away from the grains of sand. The action could be distinctly watched through a microscope focused against the inside of the tube. The fine slit and clay particles could be seen to leave the grains of sand and gather in loose light flocks in the spaces within the soil.

There seems no doubt but that the trouble with this soil was in the arrangement of the soil grains, in which the clay particles did not have their best effect in retarding the rate of flow and in making the soil sufficiently retentive of moisture. The grains were probably so arranged that some of the spaces within the soil were relatively extremely large. The ammonia changed this and caused a rearrangement of the soil grains by which they were more evenly distributed throughout the soil. It is probable that other substances would have had the same effect, and that through their judicious use the grains of clay could have been pushed a little further apart, and the soil be made as retentive of moisture as the red land and as productive and as safe a soil for cotton. This is the line in which the improvement of this land should be worked out. There is sufficient clay in the land to make it as retentive of moisture as is required in the best cotton soil, and to improve the land the object should be to push these grains of clay apart so as to change the texture of the soil.

Diagram showing the percentage of moisture in the Wedgefield soils.



Samples were taken from each of these three soils once a week during a portion of the season of 1890, and moisture determinations were made by air-drying the soils. The samples were taken to a depth of 9 inches from the surface. The preceding diagram shows the amount of moisture in the soils at the stated times.

It is to be observed that the season, as a whole, was too wet for the best development of the crop. On the red land this resulted in rather too much growth and too little fruit in proportion to the size of the plants, but the plants themselves were otherwise vigorous and healthy. On the "gummy land" and sandy land, however, the vitality of the plants was seriously impaired by the frequent and heavy rainstorms; the plants were small and were very seriously injured by lice. It happened that the rain came in very heavy and soaking storms, almost invariably three or four days before the samples were taken, and this was followed by a succession of hot, sunny days, so that the diagram does not give a true idea of the moisture in the soils, as it would if the rainfall had been more evenly distributed, or if the samples had been taken at more frequent intervals. The difference in the moisture content of these soils, as shown by the diagram, is probably amply sufficient to account for the difference in the agricultural value of the lands. When it is considered, also, that this was an unusually wet season, the amount of moisture which can be maintained for the crop by the sandy land in an average season must be very small. It is unfortunate that these records could only be extended over part of a single season.

One cannot help but think that the difference in the agricultural value of these three soils is due to the relation of the soils to water, and the amount of water which they can maintain for the crops, and that this factor, alone, determines the local distribution of crops and makes it evident why melons and sweet potatoes are admirably adapted to the "light lands," and cotton to the heavy clay or loam soils.

If it is conceded that this is the trouble with the "gummy land" it will be comparatively a simple matter to work out methods of treatment or fertilization which will overcome this trouble. It would be much easier to improve the land in this direction and to force the grains further apart than it would be to draw the grains more closely together in the impervious Potomac clays of Maryland, and make them more loamy and less retentive of moisture. It must be recognized, however, that this physical condition of the soil is the controlling cause in crop production and that any fertilization is not, or should not be, primarily, to supply plant food to the soil but to act in changing the physical structure of the land. The "best fertilizer" for this land may have little or no commercial value, or it may be any one of the high grade commercial fertilizers.

Many other interesting problems, showing the effect of the texture of the soil and the relation to water on the distribution of crops, could be given as presented by the South Carolina soils and in the cultivation of the cotton crop. Cotton is as sensitive to these conditions of heat and moisture as many greenhouse plants, and responds readily and quickly to changes in these conditions. If the season or soil is too wet, the plants are inclined to excessive growth and put on but little fruit; if too dry, the plants do not attain sufficient size but put on generally more fruit in proportion to the size of the plant and the amount of food material which has been stored up. Sudden changes of moisture or temperature lower the vitality of the plant and render it liable to disease and insect ravages. The plant is peculiarly sensitive to these physical conditions and is admirably adapted to these soil investigations.

It is to be regretted that this work could not have continued in South Carolina as the point had just been reached where a large amount of material and data had been collected to work with, but the work was, unfortunately, broken up.

MARYLAND SOILS.

We come now to speak of some problems presented by the soils of Maryland, where, it will be understood, much time has been spent in necessary preliminary work in collecting material and data. We have also to leave the study of cotton, which is so extremely sensitive to its environments, and take up the study of wheat, which is not very sensitive but which, on the contrary, readily adapts itself to marked changes in its environments, as seen in the very wide and general distribution of the plant throughout the world.

The average yield of wheat per acre for each county in Maryland, as calculated from the returns of the tenth census, is as follows:

Average yield of wheat per acre, as given in the tenth census.

	Bushels.
Southern Maryland:	
Charles	7.1
Calvert	7.6
Saint Marys	8.3
Anne Arundel	9.0
Prince George	9.0
Average	8.2
Eastern Shore:	
Worcester	7.1
Wicomico	7.2
Dorchester	7.6
Caroline	10.2
Somerset	10.3
Queen Anne	13.5
Talbott	14.1
Kent	14.8
Average	10.6

Average yield of wheat per acre—Continued.

Northern and Western Maryland:	
Allegany	8.9
Garrett	10.7
Baltimore	13.7
Carroll	14.4
Cecil	15.7
Howard	16.5
Harford	16.7
Montgomery	16.9
Frederick	16.9
Washington	18.0
Average	14.8

The state of Maryland contains approximately 10,000 square miles of land surface. It is divided geographically into four sections: Southern Maryland, having an area of approximately 2,000 square miles, has gently rolling country, and forms a peninsula with the Chesapeake Bay on the east and the Potomac River on the south and west. The Eastern Shore, containing approximately 3,000 square miles with generally level surface, having the Chesapeake Bay on the west, the Atlantic Ocean and the state of Delaware on the east, and two counties in Virginia on the south. Northern and western Maryland contain together approximately 5,000 square miles, and may be classed together here for the following study. The surface is quite rolling in northern Maryland and mountainous in western Maryland.

The largest average yield of wheat per acre, as given in the above table, is 18 bushels in Washington county. This is principally from the heavy clay lands of the Trenton chazy limestone formation of the Cumberland Valley. The lowest average yield per acre is in the lower counties on the Eastern Shore and southern Maryland. The soil on the lower part of both of these peninsulas is notoriously light and sandy. The Eastern Shore and southern Maryland belong to the Coastal Plain, and have the undisturbed and unconsolidated strata from the Jurassic to the present time. Northern-central Maryland belongs to the Piedmont Plateau, made up of the highly crystalline rocks towards the east, and semi-crystalline towards the west. Western Maryland contains the entire sequence of Paleozoic strata, in several series of folds or undulations. The geology of the Eastern Shore has not yet been worked out in any detail, and there has been no attempt to examine or classify the soils.

The soils of southern Maryland are generally light in character and texture, ranging in texture from the very light sands of the Lafayette and Columbia terrace formations, containing as little as 4 per cent. of clay in the subsoil, to the heavier lands of the Neocene formation, containing as much as 25 or 30 per cent. of clay.

The soils of northern and western Maryland have, as a rule, not less than 25 or 30 per cent. of clay, and the finest grass and wheat lands in the limestone formations have as much as 40 or 50 per cent of clay. The soils of southern Maryland are, as a rule, distinctly lighter in texture than those of northern and western Maryland, and this undoubtedly explains the low average yield of wheat in this locality, as given in the table. This is clearly recognized by practical men acquainted with the two localities. They can not judge of the difference in the chemical composition of the soil; the area of the state is so small that there can not be great differences in climatic conditions, but they will say, from the general appearance of the land, that it is not as "heavy" as the finer wheat lands of western Maryland. It is not a matter of mere plant food; it is not because the preparation and cultivation in these Eastern Shore and southern counties are less thorough, but the land itself is too "light" to maintain a larger yield of grain or a permanent sod of grass.

It is quite possible in water or sand-culture, where the conditions of moisture, temperature, and aëreation can be perfectly controlled, to add sufficient plant food to the otherwise sterile medium for the production of a normal crop. If the conditions of moisture and temperature in the light, sandy truck lands or of the pine barrens of southern Maryland are favorable for the production of wheat, then it should be possible, as in sand-culture, to produce a crop of wheat, if sufficient plant food be added to the soil. But no one would suppose for a moment that the mere addition of plant food would enable a good wheat crop to be produced on this light, sandy land. It can not be economically produced on them under existing climatic conditions, unless vast quantities of organic matter were added to the land to change the whole character and texture of the soil and make it more retentive of moisture. If the soil cannot maintain a sufficient supply of water for the crop, then this becomes a controlling factor and limits crop production. We will show that these light lands of southern Maryland are not as retentive of moisture as the heavier wheat and grass lands of northern and western Maryland, and that this follows from the lighter texture of these soils, from which the practical farmer judges of the agricultural value of the land and the kind of crop which can be economically produced. It appears, therefore, that the controlling cause in the production of crops and in the local distribution of crops in these different soil formations in the state is largely due to the texture and general physical conditions of the soil, especially to their relation to water and the amount of water which they can maintain for the crop under existing climatic conditions.

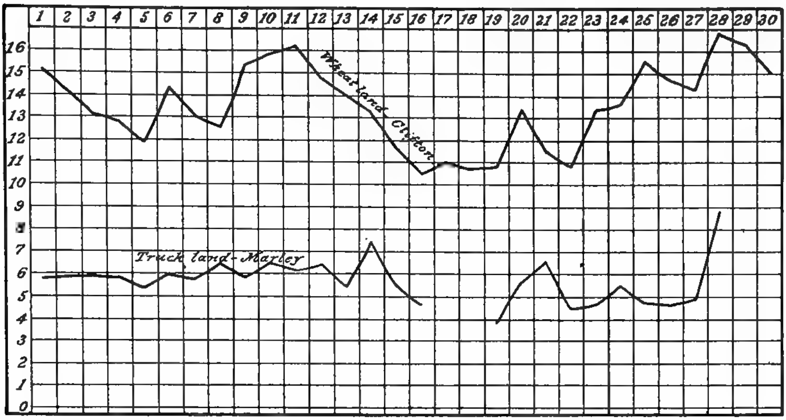
A number of stations have been established in several of the principal soil formations of the state for the study of the moisture and temperature of the soil. The soils of the different formations have markedly different texture and are widely different in their agricultural value. The stations are near volunteer observing stations of the Weather Bureau, or have the ordinary meteorological instruments supplied. They are not yet fully equipped, but are to have in addition to the above instruments a soil thermometer of a special construction, with a bulb 6 inches long, extending from 3 to 9 inches below the surface. It has a straight stem inclosed in a wooden case, as in the ordinary soil thermometer, but with maximum and minimum indices in the tube to register the highest and lowest temperature. The bulb has a special construction, devised by Professor Marvin of the Weather Bureau, to allow of the use of the two indices in the same stem. If the instrument is as successful as it gives promise of being it will be fully described at another time.

Moisture determinations are to be made in samples of the soil at the different stations, taken in small brass sampling tubes, $\frac{3}{4}$ of an inch in diameter and 9 inches long, with a mark on the side of the tube 6 inches from one end, which is the depth to which the sample is taken. Rubber caps are slipped over the open ends of the tube and it is put into a small bag and sent by mail. The moisture is determined by drying 50 grams of the sample in a porcelain dish in a water bath for five hours. The sample represents the first 6 inches in depth from the surface down. It would be well if the sample could be taken at a uniform depth of from 3 to 9 inches, or from 6 to 12 inches below the surface, but this is impracticable at these volunteer stations. It was decided that it would be impossible to secure uniform conditions if the soil were under cultivation or if any plants were allowed to grow on them, so that a small plot of land, at least 10 feet square, is reserved for this work. It is to remain undisturbed during the season, except that grass and weeds are to be removed by hand.

A convenient method is much to be desired for the determination of moisture in the soil without disturbing the natural position of the soil or removing or changing the instrument in any way. Various methods have been suggested and a number of the most promising methods were tried by Sturtevant, at Geneva, but none of them have been perfected. The writer has been trying to work out a method based on the change of electrical resistance of the soil with the changing moisture content. It is impossible, however, to get perfect contact with the soil and the plates, and it seems that this method can not be perfected. The method itself and the difficulties will be more fully discussed in another part of this report.

These moisture observations have not been continued sufficiently long to provide data for this report, but a single diagram is given showing the moisture in the soil in an open bed in the lawn at Clifton, where this work is located, and in the light, early truck lands at Marley.

Diagram showing the percentage of moisture in the wheat and truck lands.



The soil at Clifton is a fairly good wheat land, apparently about as strong as the better class of wheat lands of southern Maryland, although it belongs to an entirely different geological formation.

The soil from Marley represents the very light, early truck lands between Baltimore and Annapolis, which will be described in some detail in another part of this report. These samples were taken by Mr. T. W. Soley, of Marley, and sent by mail for the moisture determinations. Neither of the soils were cultivated nor disturbed in any way during this period.

The mechanical analysis has not been made of the soil at Clifton for the reason that the whole of the Potomac formation, to which it belongs, is extremely uneven. The moisture determinations, however, agree very closely with the moisture in samples from the Neocene wheat land at South River, which contains 17.87 per cent. of clay. The truck land from Marley has only 4.40 per cent. of clay.

The difference in the amount of moisture maintained by these two soils, as shown by the diagram, is probably amply sufficient to account for this local distribution of crops. Grass and wheat cannot be economically produced on a soil which can maintain much less water than that at Clifton, and certainly not in a soil which can only maintain as little as that at Marley.

These two localities are not over 8 or 10 miles apart in an air line, and the meteorological conditions could not have been very different. The "season" was very favorable at each place, the rainfall being rather more than the normal at both places. With the climatic conditions sensibly constant, we see here that these two soils maintain very different conditions of moisture for crops. Rain does the crop little or no good until it enters the soil. We see that one of these soils lets the rainfall pass through it readily and maintains not more than one-half or one-third as much moisture for the use of the crop as the other. Each of these conditions, if artificially maintained in a greenhouse, would be distinctly favorable to some kinds of plants and unfavorable for the proper development of others. As stated before, if the conditions in this wheat soil at Clifton are normal and necessary conditions for the growth of wheat, which can not be doubted, then this inability of the light truck land to maintain a more abundant water supply, while distinctly favorable to the early ripening of truck, is a controlling factor in the economical production of wheat, and this relation of the soil to moisture becomes as potent a factor as a controlling cause in the local distribution of crops as temperature is in the general distribution of plants.

In the arrangement and classification of the samples of soil which have been obtained in Maryland, it appears that the staple crops are distributed according to the amount of clay and the approximate number of grains per gram contained in the subsoil, if the subsoil is of sufficient depth to regulate the drainage and to give character to the land, and if the grains can be assumed to have a mean symmetrical arrangement, as in most of our great soil formations. It appears that our staple crops are distributed according to the following percentage of clay in the subsoil, which, as has been shown, largely determines the texture of the soil and the relation of the soil to moisture: Barrens, less than 4 per cent.; early truck, 4–10 per cent.; tobacco, 14–18 per cent.; wheat, 18–50 per cent.; grass, 25–50 per cent. This applies of course only to the meteorological conditions which prevail in this State and when the grains are assumed to have the same symmetrical arrangement.

THE EARLY TRUCK LANDS OF SOUTHERN MARYLAND.

There is a narrow strip of coarse, sandy soils bordering the Chesapeake Bay from Baltimore down to South River, entirely devoted to the production of early truck and vegetables for the Baltimore and the larger northern markets. This same character of soil is found along the coast as far south as Florida, and on all of it truck is raised, but it is only of the small area between Baltimore and Annapolis that these remarks have special reference.

The coarse, sandy soils and subsoils of the early truck lands between Baltimore and Annapolis contain from 4 to 10 per cent. of clay. Other things being equal, the lighter the soil and the less clay it contains the earlier the crop. Soils having over 7 per cent. of clay are rather heavy for the earliest truck, but are well suited to tomatoes, cabbages, small fruits, and peaches. Geologically these light soils belong to the Columbia terrace formation, although there are good truck lands in this area on the Eocene soils which contain not over 8 or 10 per cent of clay and are excellent for peaches and the heavier truck. A large part of this area is lying out as a barren and unproductive waste for lack of proper facilities for transportation. This matter of cheap and quick transportation is so great a factor in the trucking interest, owing to the bulky and perishable nature of the market truck and small fruits, that lands directly on the water courses have a value many times greater than similar lands situated only a mile or two from the river.

Peas, tomatoes, cabbage, sweet potatoes, watermelons, canteloupes, strawberries, raspberries, and peaches may be grown, and are grown, with more or less success on nearly all kinds of soil. But this area of coarse, sandy land in southern Maryland will produce these crops at least a week or ten days earlier than the far heavier wheat and grass lands in other parts of the state. This puts the truck into the Baltimore and northern markets much earlier than it can be produced on the heavier soils of the state, and insures the early truck farmers from competition from the state at large, and they get very fair prices, as their crops are sold before the market prices fall with the glut of summer vegetables. It requires a very heavy outlay for manuring and for labor in the trucking business, and everything depends upon their getting their crop to market at the earliest possible date to take advantage of the high prices, and no pains or expense is spared to force the maturity of the plant and hasten the ripening of the crop.

The early truck lands are much too light for the profitable production of wheat or corn, or of any of the staple crops whose period of growth extends into or through the summer months, not because the soils are deficient in plant food, but because the soils are so coarse and open in texture that they are unable to maintain a sufficient water supply for these crops during the hot spells which are liable to occur. It is not that these light, sandy lands produce as much yield per acre of the different kinds of market truck as the heavier lands that they are utilized for trucking, but that they ripen the crops earlier and so get advantage of the higher prices. There are, therefore, peculiar conditions desired in an early truck land, just the opposite conditions, indeed, from those required for a good grass or wheat soil. The soil, or rather subsoil, of the truck lands should be very light in texture, containing not over 10 per cent. of clay, and for the very earliest truck not over 6 per cent. If they have more than this, the soil is too retentive of moisture, and the growing period is prolonged and the ripening of the crop is delayed. In the truck land with less than 6 per cent of clay, the soil is drier and probably cooler, and these are conditions which would hasten the maturity of the crop.

Other things being equal, the more clay a soil contains the more retentive of moisture it will be, and the greater the amount of moisture which would be maintained in the soil for the crop. The fine particles of clay not only make the spaces within the soil exceedingly small, so that the rainfall must pass downward very slowly through the soil, but by increasing the area of the water-surface it increases the power the soil has of drawing water to the plant to supply the loss from evaporation and to replace that which has been used by the plant. In a heavy clay soil this supply of water may be so abundant as to prolong the growth of the plant and increase the size and yield per acre, but may greatly retard the ripening of the crop.

The average yield of wheat in Washington county is given by the census as 18 bushels per acre, and this is principally from a limestone soil having over 40 per cent. of clay. Wheat can not be economically produced on the light truck lands. It is not that the soils of Washington county contain necessarily more plant food than the truck lands of southern Maryland, but that having more clay the soils are stiffer and more retentive of moisture, and they can maintain a more abundant supply of water for the crop.

These limestone soils are too retentive of moisture for early truck. In an average season they would maintain such an abundant supply of water that, although large crops would be assured, the crops would be late in coming to maturity, and would come into competition with crops from all parts of the state. The light character of the land, therefore, gives the early truck planter a monopoly of the market.

The mechanical analyses of the subsoils from a number of localities will be given, with the surface area and the approximate number of grains per gram, with such notes as may be necessary on the agricultural value of these lands.

Mechanical analyses of truck subsoils from southern Maryland.

MARLEY NECK.

Diameter.	Conventional names.	471. Marley P. O.	472. Marley P. O.	591. 1 mile north of Marley P. O.	469. Glenburnie.	473. Albert Hammond.	590. 2 miles north of Marley P. O.
mm.							
2–1	Fine gravel	0.28	0.49	0.39	3.47	0.44	0.91
1–.5	Coarse sand	5.42	4.96	5.52	12.05	6.46	5.45
.5–.25	Medium sand	41.45	40.19	36.53	44.06	36.73	28.73
.25–.1	Fine sand	26.73	27.59	24.91	18.02	19.54	22.81
.1–.05	Very fine sand	12.46	12.10	11.79	9.59	10.28	13.44
.05–.01	Silt	7.22	7.74	9.89	5.73	13.42	14.77
.01–.005	Fine silt	2.21	2.23	4.51	1.37	5.61	4.29
.005–.0001	Clay	4.07	4.40	5.41	5.46	7.14	9.16
	Total	99.84	99.70	98.95	99.75	99.62	99.56
Organic matter, water, loss		0.16	0.30	1.05	0.25	0.38	0.44

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
471	Marley P. O	4.07	583	1,809,000,000
472	......do	4.40	615	1,955,000,000
591	1 mile north of Marley P. O	5.41	796	2,458,000,000
469	Glenburnie	5.46	654	2,406,000,000
473	Albert Hammond	7.14	987	3,215,000,000
590	2 miles north of Marley P. O	9.16	1,173	4,078,000,000

Mechanical analyses of truck subsoils from southern Maryland.

TICK NECK.

Diameter.	Conventional names.	585. Sandy land.	583. 1½ miles northeast of Armigers.	587. Loam.
mm.				
2–1	Fine gravel	0.45	0.28	6.06
1–.5	Coarse sand	10.33	6.09	22.09
.5–.25	Medium sand	46.29	39.48	29.87
.25–.1	Fine sand	20.15	23.00	9.82
.1–.05	Very fine sand	8.17	14.69	6.52
.05–.01	Silt	7.11	8.46	10.71
.01–.005	Fine silt	2.29	2.48	3.86
.005–.0001	Clay	4.77	5.01	7.89
	Total	99.76	99.45	96.82
Organic matter, water, loss		0.24	0.55	3.18

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
585	Sandy land	4.77	629	2,121,000,000
583	1½ miles northeast of Armigers	5.01	673	2,185,000,000
587	Loam	7.89	987	3,621,000,000

The soils from Marley Neck, having less than 6 per cent. of clay, as shown by the table, are considered very typical early truck lands. 473 is from a ridge of rather heavier land, having 7.14 per cent. of clay. The land where this sample was taken is considered rather heavy for the very early truck, but is excellent land for small fruits. The same may be said of 590, although less is known of this sample.

On Tick Neck, also, we find that the very earliest truck lands have less than 6 per cent. of clay. The sample of loam, 587, was taken far down on the point, in what is considered the garden spot of the truck area. There is a narrow strip of this loam soil extending along the bay shore and covering the points of these river necks. This strip is from one-half a mile to a mile wide, and contains considerable gravel in the subsoil about 2 feet below the surface. There are only small areas of the lighter sandy land containing less than 6 per cent. of clay. By reason of the location on the bay shore, with rivers and creeks making up in all directions into the farms, the climatic conditions are peculiarly mild and the truck planters are insured against frost. They can plant earlier so that these loam soils are as early, or earlier, than the light lands further up the river necks, represented by the other two samples in the table, although it is recognized by the truck planters that the period of growth is somewhat longer, and under exactly the same climatic conditions the crops would be later in coming to maturity on this loam soil than on the lighter sandy lands. It is, of course, a distinct advantage, however, to have both the heavier soil, which will produce more crop per acre, and the favorable situation nearly surrounded by water to insure against frost and to allow the crops to be planted earlier.

Mechanical analyses of truck subsoils from southern Maryland.

ROCK POINT.

Diameter.	Conventional names.	579.	581.
		Jas. Meek.	½ mile north of McCubbins.
mm.			
2–1	Fine gravel	0.09	0.56
1–.5	Coarse sand	2.31	4.83
.5–.25	Medium sand	31.18	27.49
.25–.1	Fine sand	25.49	16.36
.1–.05	Very fine sand	16.92	12.51
.05–.01	Silt	12.86	22.39
.01–.005	Fine silt	3.82	5.03
.005–.0001	Clay	6.33	10.12
	Total	99.00	99.29
Organic matter, water, loss		1.00	0.71

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
579	James Meek	6.33	886	2,850,000,000
581	½ mile north of McCubbins	10.12	1,348	4,471,000,000

The two samples from Rock Point contain rather more clay than from the other localities, but very little is known of the agricultural features of these soils. 581 came from a ridge, and would be regarded as a decidedly heavier soil than 579, and better suited to small fruit.

Mechanical analyses of truck subsoils from southern Maryland.

NORTH MAGOTHY NECK.

Diameter.	Conventional names.	561.	563.	565.	567.	577.	589.	575.	571.	569.	573.
		Armiger.	Armiger.	2 miles west of Armiger.	1 mile west of Armiger.	J. M. Cook.	2 miles north of Armiger.	J. M. Cook, loam.	Dr. E. Williams, loam.	Dr. E. Williams, loam.	J. M. Cook, gravelly loam.
mm.											
2–1	Fine gravel	0.74	0.39	2.12	2.46	1.52	2.33	1.26	0.34	0.87	3.67
1–.5	Coarse sand	7.13	7.04	8.81	13.32	4.50	26.08	8.91	2.97	5.82	11.92
.5–.25	Medium sand	36.21	37.51	31.35	39.83	29.88	33.06	47.84	21.18	26.22	29.99
.25–.1	Fine sand	22.82	21.45	22.82	14.14	23.77	10.18	6.29	18.19	17.55	6.35
.1–.05	Very fine sand	14.15	13.45	16.76	9.34	10.36	4.71	6.29	17.17	16.34	5.56
.05–.01	Silt	9.26	10.72	10.19	10.17	17.16	13.14	15.08	21.05	16.33	21.91
.01–.005	Fine silt	4.68	3.72	2.08	3.29	3.83	3.58	5.76	9.57	7.45	6.21
.005–.0001	Clay	4.71	5.41	5.47	6.36	8.01	8.29	8.33	8.39	8.52	12.84
	Total	99.70	99.69	99.50	98.91	99.03	102.39	99.92	98.86	99.10	98.45
Organic matter, water, loss		0.30	0.31	0.50	1.09	0.97	......	0.08	1.14	0.90	1.55

Mechanical analyses—Continued.

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
561	Armiger	4.71	727	2,137,000,000
563	......do	5.41	769	2,427,000,000
565	2 miles west of Armiger	5.47	721	2,429,000,000
567	1 mile west of Armiger	6.36	824	2,856,000,000
577	J. M. Cook	8.01	1,060	3,596,000,000
589	2 miles north of Armiger	8.29	961	3,587,000,000
575	J. M. Cook, loam	8.33	1,102	3,676,000,000
571	Dr. E. Williams, loam	8.39	1,296	3,862,000,000
569	......do	8.52	1,204	3,869,000,000
573	J. M. Cook, gravelly loam	12.84	1,562	5,779,000,000

Of the samples collected on North Magothy Neck, the first four are typical early truck lands. They are very coarse, sandy soils, and in their natural condition they are little more than barren wastes. Under the peculiar and intense conditions of manuring and cultivation, however, they are admirably adapted to early truck and they are classed as the very earliest truck lands of the locality. 569 and 571 are of a loam soil from a ridge, similar to the ridge on Marley Neck where sample 573 was secured. Off of this ridge and down near the Magothy River, but on the same farm, the light lands prevail, containing not over 5 per cent. of clay in the subsoil. Dr. Williams stated that these light lands were his earliest truck soils, and that tomatoes, for example, will ripen at least a week earlier on the light lands than on the loam soil. Tomatoes and cabbages do better and yield more per acre on the loam soil, but they are not so early and, consequently, do not bring as good prices as the crops from the lighter soils. Time is everything to the early truck planter, and these light lands have some peculiar property which adapts them to this early truck and matures the crop earlier than on any other soils of the state. The loam soils are much better adapted to small fruits and peaches than the very light lands.

At the extreme end of Magothy Neck there are the same loam soils referred to in speaking of the soils of Tick Neck, of which 573 is considered a representative sample from this locality. There is considerable gravel in the subsoil about 2 feet below the surface. 575 and 577 are from lighter lands on the upper part of the same farm. These lighter soils are earlier than the heavier loam, but, by reason of the locality right on the bay shore and with rivers and creeks making up into the farm in all directions, this loam soil (573) is considered earlier than the loam soils at Dr. Williams, and probably as early as the lighter truck lands at Armiger. It is considered excellent for peaches and for truck, as it produces more per acre than the light lands, and, by reason of the location near the bay shore, the crop can be planted earlier and so will mature earlier than on even lighter lands further up the river neck.

Mechanical analyses of truck subsoils from southern Maryland.

SOUTH PATAPSCO NECK.

Diameter.	Conventional names.	467. Shipley.	476. Furnace Branch.
mm.			
2-1	Fine gravel	0.76	*2.80
1-.5	Coarse sand	8.55	8.36
.5-.25	Medium sand	35.04	26.11
.25-.1	Fine sand	19.26	10.72
.1-.05	Very fine sand	8.42	10.15
.05-.01	Silt	11.38	17.98
.01-.005	Fine silt	4.13	8.76
.005-.0001	Clay	10.59	11.60
	Total	98.13	96.48
Organic matter, water, loss		1.87	3.52

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
467	Shipley	10.59	1,244	4,767,000,000
476	Furnace Branch	11.60	1,549	5,386,000,000

* Including 1.08 per cent. larger than 2 millimeters.

The two samples from South Patapsco Neck show a larger percentage of clay than the lighter truck lands, and these soils are recognized as heavier lands and rather later than the early truck lands of Marley and Magothy. It is a great truck region, however, because it is adjacent to Baltimore, and the truck and vegetables can be taken to market by wagon at very much less expense and in better condition than if they were sent by boat or rail. These lands, also, can be depended upon for a constant supply of truck throughout the season, and while they come in competition more with truck from other parts of the state, still they have the advantage of more direct communication with the markets. Many of the truckers from this locality sell their products directly, without the intervention of middlemen or agents.

Mechanical analyses of truck lands from southern Maryland.

Diameter.	Conventional names.	270. South River Neck.	268. J. Birch.	145. Patuxent River.
mm.				
2-1	Fine gravel	0.32	0.04	1.78
1-.5	Coarse sand	5.81	1.97	7.63
.5-.25	Medium sand	40.63	28.64	38.35
.25-.1	Fine sand	28.93	39.68	21.80
.1-.05	Very fine sand	9.44	11.43	6.87
.05-.01	Silt	4.60	4.95	11.73
.01-.005	Fine silt	2.04	2.02	2.48
.005-.0001	Clay	7.63	8.79	7.92
	Total	99.46	97.52	98.56
Organic matter, water, loss		0.54	2.48	1.44

Mechanical analyses—Continued.

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
270	South River	7.63	903	3,450,000,000
268	J. Birch	8.79	1,007	3,955,000,000
145	Patuxent River	7.92	955	3,549,000,000

The two soils from South River Neck, represented in the table, are excellent truck lands and are particularly well adapted to peaches. The same may be said in a general way of the Patuxent River soils, but owing to the difficulty of transportation the soils represented by 145 have not been much improved.

These truck lands appear to be remarkably uniform in texture, and the slight differences, which appear in the percentage of clay and in the approximate number of grains per gram, are very sharply defined in the agricultural value and importance of the land. The soils having the lowest percentage of clay and the least number of grains per gram are, with the exception of those directly on the bay shore at the end of the river necks, invariably regarded as the earliest truck lands, and one can readily tell from the general appearance and texture of the soil to what class of lands the sample belongs. The light soils mature the crop earlier, but the heavier loam soils produce a larger yield per acre and generally a better development, and would be considered naturally stronger soils.

These soils are all too light for the profitable production of the staple crops, as the yield per acre would be extremely small and they could not compete with the stronger and heavier soils from other parts of the state and of the country. Their peculiar value lies in the fact that they can produce, during the spring and early summer, small fruits and vegetables earlier than they can be produced in other parts of the state, so that they have the advantage of good market prices. The reason for this is undoubtedly due to the physical structure of these soils, especially to the relation of the soils to water. It cannot be due directly to the amount of available plant food they contain, for no addition of mere plant food would make these soils as strong and productive as a limestone soil, unless the whole texture of the land was changed.

It has been shown in a diagram, page 53, that these light sandy soils can maintain, on an average, not more than 5 or 6 per cent. of water, and it has been shown that a good wheat land must maintain not less than 12 or 15 per cent. of water, and probably a good strong grass land should be able to maintain much more than this. These moisture determinations were made at Marley, near where samples 471 and 472 were taken.

A determination was made of the actual rate of movement of water through the subsoil in its natural position in the field, on Tick Neck, near where sample 583 was taken. The subsoil contains 37.29 per cent. of empty space and it took 3 minutes and 15 seconds for one inch in depth of water to pass through 3 inches in depth of subsoil, with an initial pressure of 2 inches in depth of water.

A determination was made of the rate of flow through the saturated soil at Armiger (563). The subsoil contained 41.25 per cent. of empty space and it took 2 minutes and 30 seconds for one inch in depth of water to pass through 3 inches in depth of subsoil, with an initial pressure of 2 inches of water.

A determination was made of the rate of flow through the saturated subsoil at Marley, near where samples 471 and 472 were taken. The subsoil contained 55.77 per cent. by volume of empty space; more than the samples from the other localities. An inch in depth of water passed through 3 inches in depth of the saturated subsoil in 1 minute and 30 seconds, under an initial pressure of 2 inches of water. In the wheat lands, as we will see later, the actual time required for an inch in depth of water to pass through 3 inches in depth of subsoil is very much longer than this, (43 minutes and over).

Stable manure is considered the very best fertilizer for these truck lands, and where this can be secured it is applied to the lands in large quantities. Lime is also largely used, but there must be sufficient organic matter in the soil for the lime to act on or it will "burn out" the land. Both the stable manure and lime, as we shall see later, would tend to make these soils more retentive of moisture, but the soils are so coarse and open in texture that large quantities of manure may be applied without fear of clogging the soil, and the effect of such manuring would be felt but a short time.

TOBACCO AND WHEAT LANDS OF SOUTHERN MARYLAND.

Tobacco and wheat have been staple crops in southern Maryland for many years. A grade of tobacco was produced there well adapted to the French and German markets, and large orders were placed with the Baltimore merchants for both of these countries.

It is claimed now that the lands have deteriorated from the continued cultivation of tobacco, and the quality of the tobacco is not so good as it was only a few years ago. Good prices may still be obtained for a good quality of leaf, but the prevailing prices are very low, as there is little market for the quality of tobacco generally produced.

It is claimed that the deterioration of these tobacco lands is largely due to lack of proper cultivation, owing to the scarcity and high price of labor, and to the lack of proper fertilization.

The wheat lands of southern Maryland, as stated in a previous section, are lighter in texture than the wheat and grass lands of northern and western Maryland, and the average yield per acre is much less. It is claimed that these wheat lands have deteriorated within recent years for lack of proper preparation and treatment of the land, due to the scarcity and high price of labor, to the low price of wheat, and to the fact that much of the land has been heavily mortgaged for the past twenty-five years.

It used to be the rule to apply lime every five years, and to depend on this and clover to keep up the land, but this rule is being neglected. Lime is applied more rarely, as there is little money to spend on fertilization, and the lands are becoming clover-sick.

This deterioration of the lands can not be due solely to loss of plant food, for the deterioration is accompanied by a marked change in the texture and appearance of the land, which is very apparent to the eye. There is the greatest possible difference in the appearance of a well kept field and of a soil which has deteriorated. Some very interesting problems are presented in the changes which evidently occur in the texture of these lands in the deterioration of soils, or in the improvement of such as have been once worn out and abandoned.

The wheat soils of southern Maryland appear to be confined principally to the Neocene formation, and to the terraces bordering the rivers in the lower part of the peninsula, which are classed with the Columbia terrace formation, although the soil is very different from the light, sandy, truck lands of the Columbia formation bordering the bay. Tobacco is produced on both of these formations, and also on the Eocene soils. By far the largest and most important area of the wheat and tobacco lands, however, is in the Neocene formation, and it is those lands which will be considered here.

Wheat and tobacco are commonly grown on the same land, in rotation periods of two or three years. The best lands for wheat, however, are the heaviest clay lands, while the finest quality of tobacco is produced on the lighter loams. The heavy clay lands produce a larger yield of tobacco per acre, but the plant has a coarse, thick leaf, which is sappy, and which cures green and will not take on color. The finest grade of tobacco is produced on the lighter loam soils, which are rather too light for the profitable production of wheat. The tobacco produces a small yield per acre on these soils, but the leaf has a fine texture, and in curing it takes on a good color and brings a much better price in the market. As a rule, the lighter the soil in texture the finer the quality of tobacco produced and the higher price it will bring per pound, but the less yield there will be per acre, so that there is a limit in the profitable production of the very finest grades on the very lightest lands, as the price is not sufficient to cover the small yield per acre.

The accompanying table gives the mechanical analyses of the subsoils of tobacco lands from a number of localities in southern Maryland:

Mechanical analyses of subsoils from southern Maryland, rather light for wheat but the finest tobacco lands.

Diameter.	Conventional names.	266. Chaneyville.	258. Marlborough.	164. North Keys.	260. Nottingham.	262. Chaneyville.	162. Marlborough.
mm.							
2-1	Gravel	1.40	1.53	0.58	0.48	0.00	0.09
1-.5	Coarse sand	2.94	5.67	0.50	3.05	0.07	0.13
.5-.25	Medium sand	11.23	13.25	1.35	12.08	1.56	0.58
.25-.1	Fine sand	13.42	8.39	10.65	12.09	13.51	4.90
.1-.05	Very fine sand	19.32	14.95	37.71	19.17	37.73	26.78
.05-.01	Silt	17.59	28.86	22.00	23.09	18.82	33.12
.01-.005	Fine silt	5.44	7.84	7.81	8.74	6.18	8.24
.005-.0001	Clay	10.72	14.55	16.02	18.42	18.79	21.81
	Total	97.06	95.04	96.72	97.12	96.67	95.65
Organic matter, water, loss		2.94	4.96	3.28	2.88	3.33	4.33

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
266	Chaneyville	10.72	1,370	4,891,000,000
258	Upper Marlborough	14.55	1,902	6,786,000,000
164	North Keys	16.02	2,016	7,338,000,000
260	Nottingham	18.42	2,126	8,263,000,000
262	Chaneyville	18.79	2,197	8,530,000,000
162	Upper Marlborough	21.81	2,638	10,065,000,000

The finest quality of tobacco is produced on the soils shown to have the smallest amount of clay and the smallest number of grains per gram in this table, while the heavier soils are much better for wheat and give a larger yield of tobacco per acre, but the quality of the tobacco is not so good, and it does not bring as good a market price. With the exception of 162, none of these soils would be considered very good wheat lands with the ordinary conditions of cultivation and manuring. They would be considered rather too light for the economical production of wheat. These lands are valued for wheat in proportion to the amount of clay contained in the subsoils, as shown in the table, but for tobacco the values are just reversed.

The strongest and best wheat lands appear to be confined to the diatomaceous earth horizon of the Neocene formation. The white diatomaceous earth can be found a few feet below the surface at all, or nearly all, the localities represented in the accompanying tables. The yellow clay of the wheat land appears to have been formed by the weathering of this earth, as in a number of railroad cuts and river bluffs they are seen to merge together, and in all cases where air has had access to the diatomaceous earth through cracks and root holes, a thin layer of the yellow clay has been formed. Diatoms are still found in most of these samples of the subsoils of the wheat and tobacco lands.

There are two classes of wheat lands. On the ridges and high plateaus, where washing has not occurred to any extent, the lands are rather light and loamy, the loam being usually from 2 to 4 feet thick and overlying the heavier clay. These lands are better for corn than the heavier lands, but are not so good for wheat and are too light in texture for grass. Where the underlying clay is exposed, as in the gently rolling lands, it makes a much stronger and better wheat soil and good grass land. The accompanying table gives the mechanical analyses of the subsoils from a number of localities, which represent very fairly the wheat lands of southern Maryland:

Mechanical analyses of subsoils of wheat lands from southern Maryland.

Diameter.	Conventional names.	250. Chaneyville, J. F. Talbott.	248. Davidsonville, P. H. Isreal.	245. Davidsonville, opposite church.	180. Plum Point.	155. Upper Marlborough.	246. ½ mile west of Davidsonville.	141. Davidsonville, loam, T. S. Iglehart.	252. South River.	184. Popes Creek.
mm.										
2-1	Gravel	0.00	0.00	0.82	0.00	0.00	0.00	0.00	0.00	0.00
1-.5	Coarse sand	0.07	0.22	0.28	0.00	0.40	0.56	0.23	0.25	0.46
.5-.25	Medium sand	0.98	2.76	0.98	0.48	0.57	31.26	1.71	3.39	6.61
.25-.1	Fine sand	12.22	12.85	1.74	3.06	22.64	4.62	6.08	10.65	12.19
.1-.05	Very fine sand	29.58	47.13	52.74	50.32	30.55	30.70	30.82	29.05	9.15
.05-.01	Silt	23.19	12.89	16.91	14.19	13.98	26.16	20.92	22.45	30.89
.01-.005	Fine silt	10.13	4.07	3.35	6.78	4.08	9.44	11.21	6.56	13.22
.005-.0001	Clay	19.14	19.19	19.57	20.28	21.98	22.53	23.78	23.92	24.45
	Total	95.31	99.11	95.82	95.11	94.20	95.27	94.75	96.27	96.97
Organic matter, water, loss		4.69	0.89	4.18	4.89	5.80	4.73	5.25	3.73	3.03

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
250	Chaneyville	19.14	2,453	8,918,000,000
248	Davidsonville, P. H. Isreal	19.19	2,097	8,452,000,000
245	Davidsonville	19.57	2,214	8,917,000,000
180	Plum Point	20.28	2,380	9,357,000,000
155	Upper Marlborough	21.98	2,493	10,228,000,000
246	½ mile west of Davidsonville	22.53	2,732	10,456,000,000
141	Davidsonville, loam, T. S. Iglehart	23.78	2,853	11,161,000,000
252	South River	23.92	2,681	10,933,000,000
184	Popes Creek	24.45	2,847	11,202,000,000

These lands make fairly good wheat lands, but it is about the limit of profitable wheat production, and a soil having less than 20 per cent. of clay, or approximately 9,000,000,000 grains per gram, is too light in texture and not sufficiently retentive of moisture for the economical production of wheat under the prevailing climatic conditions. This represents, however, merely the skeleton structure of the soil, and this could be so filled in and modified as to make it more productive, but experience has shown that a soil lighter than this has not sufficient body to warrant the expense of converting it into a good wheat land. The soils are too light for grass. They are valued as wheat lands about in the order in which they are given in the table, except that it would seem that 245 should have been given a higher place in the table, as it is considered a very fertile wheat land, but this may have been due to the sampling.

A determination was made of the time required for water to pass through the subsoil at South River, near where 252 was collected. The subsoil was found to contain 51.48 per cent. by volume of empty space. One inch in depth of water passed through 3 inches in depth of saturated subsoil in 43 minutes, with an initial pressure of 2 inches in depth of water.

The samples in the accompanying table are of strong wheat and grass lands of southern Maryland. They are considered the very finest type of wheat lands in that locality:

Mechanical analyses of subsoils of strong wheat and grass lands from southern Maryland.

Diameter.	Conventional names.	142. Davidsonville, clay.	247. Davidsonville, James Iglehart	179. Herring Bay.
mm.				
2–1	Fine Gravel	0.00	0.00	0.00
1–.5	Coarse sand	0.00	0.27	0.00
.5–.25	Medium sand	0.29	0.64	0.50
.25–.1	Fine sand	2.43	3.20	3.50
.1–.05	Very fine sand	23.56	22.58	36.28
.05–.01	Silt	29.23	26.25	19.04
.01–.005	Fine silt	6.36	10.42	6.78
.005–.0001	Clay	32.45	32.40	32.42
	Total	94.32	95.76	98.52
Organic matter, water, loss		5.68	4.24	1.48

No.	Locality.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
142	Davidsonville, clay, T. S. Iglehart	32.45	3,604	15,148,000,000
247	Davidsonville, James Iglehart	32.40	3,537	14,903,000,000
179	Herring Bay	32.42	3,389	14,433,000,000

These three samples were taken from very rolling lands, where the loam, if it had ever accumulated, had been removed by washing, leaving exposed the yellow clay which seems to underlie all the wheat lands.

Very recently the U. S. Geological Survey has made a geological survey of this locality, and from a manuscript map which they have kindly supplied it would appear that they have been able to separate the Neocene formation in this locality into Lafayette and Chesapeake. The Lafayette is shown as covering the high hills and plateaus, apparently where our loam samples were secured. The Lafayette formation is hardly more than 2 to 4 feet thick at this place, and is made over out of the diatomaceous earth material, which would account for the diatoms found in the subsoil. The Lafayette formation covers the ridge lands further down the peninsula with the coarse, sharp sand of the pine barrens. This geological data will necessitate a further and more careful collection of soil samples in this locality, to see if these two grades of wheat land correspond closely with the two horizons of the Neocene formation; but this whole work shows the intimate relation of geology to agriculture, in the area and distribution of the principal soil formations and the necessity of thorough geological work as a basis for soil investigations.

There is a very marked relation between the agricultural value of these lands and the texture and general appearance of the soils. If the soils are in a moderate condition of cultivation, in which the arrangement of the grains can be assumed to be sensibly constant, the agricultural value increases quite regularly with the percentage of clay, and the approximate number of grains per gram. The yield increases, however, in nearly all cases, and with most crops, at the expense of the quality of the crop produced. In the case of tobacco and truck, as the quality or time of maturity is of more importance than the quantity of crop produced, the lands are valued, within certain limits, as the soil is lighter in texture and contains less clay and fewer grains per gram. It is not a matter of the chemical composition of the soil, or of the amount of available plant food in the soil, which determines this local distribution of crops, but it is a matter of the texture of the soil and especially of the relation of the soils to water, and the amount of water which they can maintain for the crop under existing climatic conditions.

Lime has been considered the very best fertilizer for these wheat lands, but lime with plenty of organic matter in the soil "for the lime to act on," otherwise, it will "burn out the land," so that where lime is applied, as it should be every few years, clover or some green manuring is considered a necessary adjunct. We shall see that this combination would tend to make the soils more retentive of moisture.

There has always been a peculiar prejudice against the use of high grade fertilizers in southern Maryland. They are rarely used on the wheat lands, especially where lime and clover can be applied. Large quantities have been used on the tobacco lands, but the deterioration of these tobacco lands is very frequently attributed to the use of the high grade fertilizers.

When Peruvian guano was introduced, as one of the first of the high grade fertilizers, it was used quite freely for tobacco, but it was claimed that it was, in the end, injurious to the lands. It was said that for the first two or three years it acted as a stimulant and increased the yield of crop, but that the land soon became exhausted and was poorer than before. There has been no general recognition of this fact by agricultural chemists, for it has been argued that the continued application of plant food could not impoverish a soil, but it would certainly seem that the farmers were right in this, and that the injudicious use of high grade fertilizers may very likely have a permanent effect upon these soils, by changing the arrangement of the soil grains and changing the relation of the soils to water, which would be highly injurious to succeeding crops. This matter presents one of the most interesting problems in these soil studies of southern Maryland.

The samples which have been described and of which the mechanical analyses have been given in the foregoing tables, are of representative soils and from what is considered to be typical and representative localities of the different soil formations. Other samples have been collected of local interest, and there is a considerable amount of material on hand for the study of the change in texture which has evidently occurred in the deterioration of some of these lands, but there has been no time to work them up for this report.

WHEAT LANDS OF THE RIVER TERRACES.

The accompanying table gives the mechanical analyses of the subsoils from four localities of the fertile river terraces of southern Maryland:

Mechanical analyses of subsoils of wheat land.

RIVER TERRACE.

Diameter.	Conventional names.	199.	201.	203.	205.
		Benedict.	St. Marys.	St. Marys.	Opposite. St. Marys.
mm.					
2-1	Fine gravel	0.38	0.44	2.01	0.41
1-.5	Coarse sand	2.72	1.05	5.24	0.42
.5-.25	Medium sand	11.64	2.67	1.75	1.64
.25-.1	Fine sand	7.23	5.03	2.17	3.45
.1-.05	Very fine sand	6.74	9.75	2.45	9.48
.05-.01	Silt	33.92	34.82	37.21	41.88
.01-.005	Fine silt	10.62	14.52	15.52	11.98
.005-.0001	Clay	23.45	25.03	29.27	26.24
	Total	96.70	93.31	95.62	95.50
Organic matter, water, loss		3.30	6.69	4.38	4.50

No.	Locality.	Clay.	Surface. area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
199	Benedict	23.45	2,765	10,737,000,000
201	Saint Marys	25.03	2,889	11,936,000,000
205	Opposite Saint Marys	26.24	3,188	12,205,000,000
203	Saint Marys	29.27	3,509	13,578,000,000

These river terraces border the Potomac River and its tributaries in the lower part of the peninsula, and are considered very strong wheat lands. They are classed geologically with the Columbia terrace formation, but, as will be seen from the mechanical analyses and as shown from the agricultural value of the lands, they are very much stronger soils than those of the same formation on the bay shore, which form the early truck lands between Baltimore and Annapolis. The terraces have an elevation of from 20 to 60 feet above tide and are about ½ mile wide, with the Lafayette formation rising beyond this into the pine barrens of the higher lands further inland. The lands have good body and are capable of a very high state of cultivation, and many of them are maintained in a very good condition. Some of the land around Saint Marys has been under cultivation for two hundred years without apparent deterioration, although there is nothing at all peculiar in the appearance of the land to indicate any unusual conditions. The soil is about 6 or 8 inches deep, but neither the soil nor subsoil appear to have more organic matter than is usual in the lands of southern Maryland, nor do they appear different from the same class of lands elsewhere. They have been taken care of and have been very intelligently handled.

TRUCK AND WHEAT LANDS FROM SHIPLEY.

Very interesting conditions, showing the relation of the texture of the soil to the local distribution of plants, are presented in the soils represented by their mechanical analyses in the accompanying table:

Mechanical analyses of truck and wheat subsoils—W. A. Shipley, Shipley Station.

Diameter.	Conventional names.	472. Early truck, Marley.	467. Truck and small fruit.	478. Peas, tomatoes, cabbage, wheat.	480. Strong wheat and grass.
mm.					
2–1	Fine gravel	0.49	0.76	2.05	0.00
1–.5	Coarse sand	4.96	8.55	3.31	0.38
.5–.25	Medium sand	40.19	35.04	5.41	1.07
.25–.1	Fine sand	27.59	19.26	2.89	0.78
.1–.05	Very fine sand	12.10	8.42	6.06	3.41
.05–.01	Silt	7.74	11.38	40.15	43.08
.01–.005	Fine silt	2.23	4.13	13.14	13.81
.005–.0001	Clay	4.40	10.59	23.84	30.21
	Total	99.70	98.13	96.85	92.80
Organic matter, water, loss		0.30	1.87	3.15	7.20

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
472	Early truck, Marley	4.40	615	1,950,000,000
467	Truck and small fruit	10.59	1,244	4,767,000,000
478	Peas, tomatoes, cabbage, wheat	23.84	2,242	10,923,000,000
480	Strong wheat and grass	30.21	3,479	14,457,000,000

472 represents the very early truck lands of Marley, which have already been described. Marley is about 3 or 4 miles in a direct line

from Shipley Station. The other three soils are all at Shipley Station, and are on the same farm and are only a few hundred feet apart, so that all the soils are under the same meteorological conditions. 480 is a strong grass and wheat land, from a ridge having an elevation of about 160 feet. This sample was taken in a heavy grass sod which has stood for a number of years. It would be classed anywhere as a strong wheat soil and a very good grass land. 478 came from a level plateau or terrace, just under the ridge, and was evidently formed of the same material. It is a much lighter soil than that on the top of the ridge, but is still a good wheat land. It is too heavy for early truck and for sweet potatoes and canteloupes. It is considered good tomato, corn, and cabbage land, although it does not ripen the crops so early as the lighter soils. Peas do well on this land, but they cannot be grown two years in succession, for the large amount of nitrogenous matter in the roots and vines makes the soil very close and heavy, and the second year there is a large amount of pea vines but a very small crop of peas is obtained from them. Wheat is nearly always sown after the peas, then grass, followed by corn, and then peas again. Some such rotation as this is necessary to keep the land open and in good condition. 467 is the regular truck land of this locality, well suited to truck and small fruit. It is a coarse, sandy soil, but not so light in texture nor as early as the lands at Marley. The productiveness of these lands increases with the amount of clay they contain and the number of grains per gram.

It cannot be doubted that the local distribution of plants on these soils is due to the texture of the land, and very largely upon the relation of the soils to water. No better illustration can be found of the fallacy of a very common impression of the theory of fertilization than in these soils. It is not that the strong clay soil (480) is necessarily deficient in any particular kind of plant food that sweet potatoes and canteloupes cannot be successfully grown, and further, if sweet potatoes and canteloupes are to be grown upon this land the conditions of treatment should be just the reverse of what would be required for the best development of wheat. For the melons the soil must be made more loamy and less retentive of moisture, while for wheat and grass the soil must be made, if anything, closer and more retentive of moisture. Tomatoes raised on a heavy soil, like (480), in which there is such an abundant water supply, would be likely to run to weed, that is, to produce a very large and rank growth of vine but with little fruit, and it would be late in coming to maturity, just as in a greenhouse a florist can make a geranium bloom quite freely by keeping the soil rather dry, or he can push it to a luxuriant development of foliage, with no tendency to flower, by keeping the soil more moist. Obviously, the same treatment could not be expected to have the same results for all crops on any one of these soils, and the same plant might require very different conditions of manuring and treatment on these four different soils.

It would be admitted by practical men that 467 is well adapted to small fruits, but that 472 is rather light in texture and 480 is too heavy for the best development of such a crop. Obviously, the treatment best adapted to one soil would not give the same results on the other, for the conditions of growth which it is desired to secure would be a mean between these two extremes.

SAMPLES OF CLAY.

Very interesting conditions are found in the Potomac formation; a narrow belt of barren clay hills extending across the state from Washington through Baltimore to the Delaware line. These variegated clays are so close in texture as to be almost impervious to water, and quite unsuited to the growth of agricultural crops. The movement of water through them is so extremely slow that a plant would suffer for lack of sufficient water while the soil might show a high water content. The clay is used at the potteries for burning both porous tile and stoneware, and it is so impervious to water that it is used for puddling and for diverting water from the gutters in the repair of streets.

The accompanying table gives the mechanical analyses of three samples of clay:

Mechanical analyses of samples of clay.

Diameter.	Conventional names.	304. Red clay, tile.	305. Red clay, puddling.	288. Helderberg limestone.	303. Blue clay; stoneware. *
mm.					
2–1	Fine gravel	0.00	0.31	1.34	0.00
1–.5	Coarse sand	0.00	0.82	0.33	0.00
.5–.25	Medium sand	0.50	2.69	1.08	0.29
.25–.1	Fine sand	2.63	3.23	1.02	1.27
.1–.05	Very fine sand	9.62	8.89	6.94	8.93
.05–.01	Silt	25.13	26.17	29.05	20.16
.01–.005	Fine silt	13.44	11.18	11.03	16.72
.005–.0001	Clay	42.34	42.36	43.44	50.02
	Total	93.76	95.65	94.23	97.39
Organic matter, water, loss		6.24	4.35	5.77	2.61

No.	Soil.	Clay.	Surface area.	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
304	Red clay, tile	42.34	4,737	20,072,000,000
305	Red clay, puddling	42.36	4,566	19,447,000,000
288	Helderberg limestone	43.44	4,575	19,638,000,000
303	Blue clay, stoneware	50.02	4,905	22,639,000,000

There is also given, for comparison, the mechanical analysis of a very strong and fertile wheat subsoil of the Lower Helderberg formation. It will be seen that this is almost identical in texture with the red clay used in puddling. The impervious clays have no more of this fine material in the clay group, and no more grains per gram than the limestone soil, but the one is too close in texture and too retentive of moisture, and will dry into a hard, stone-like mass, while the other, although a strong clay soil, is friable and readily permeable to water.

A few drops of strong ammonia added to the water which passes through the limestone soil will make this quite as impervious as the other clays, and this change in the texture of the soil will be due to a rearrangement of the soil grains, the change being quite apparent to the eye. There is no question but that the trouble with these impervious clays is that they are too close and too retentive of moisture, and that this is due, not to an unusual amount of clay, but to the arrangement of the soil grains. To increase the agricultural value of these lands they must be made lighter in texture and less retentive of moisture, and this can probably be done by the judicious use of fertilizers and manures, accompanied by underdrainage and proper conditions of tillage and cultivation; on the other hand, it will be no very difficult thing, by injudicious fertilization or treatment of the land, to convert the limestone soil into an impervious clay which would be turned out as a barren waste.

The whole problem of the soils, as presented in southern Maryland, makes it appear that the deterioration of lands is due to or is accompanied by a change in the arrangement of the soil grains, changing the relation of the soil to the circulation of the water. This change in the appearance or texture of the land is quite apparent to the eye, and one can judge of the condition of the land by the general appearance of the soil.

It would appear as a result of this work that the subsoil of good grass land under prevailing climatic conditions should contain not less than 30 per cent. of clay, or about *twelve thousand million* grains per gram, good wheat land not less than 20 per cent. of clay, or about *nine thousand million* grains per gram, and early truck not over 10 per cent., or about *four thousand million* grains per gram; *provided,* these grains have a certain mean arrangement, and that this skeleton structure contains an average amount of organic matter.

It has taken a long time to collect this material and arrange and classify it to give a basis for further work. It has not been possible to go over the field and make the actual determinations of the rate of flow of water through these subsoils, except in the few cases which have been given, and in working up the methods in the laboratory. This is the most important work to be taken up, now that the material has been collected, and if the opportunity is given this will be the next line of work to be undertaken, to study the actual relation of these soil formations to water and the effect thereon of manures and fertilizers.

Until this work is done and the actual determinations of the rate of flow can be given it will be unnecessary to give in detail the calculated relative rate of movement of water through these different soils.

There has not been sufficient work done as yet in the soils of western Maryland to permit of a fuller discussion than will be given in the type samples.

TYPE SUBSOILS.

A number of type samples have been prepared and analyzed, showing the average composition of all the samples collected from the principal agricultural soils in southern and western Maryland, as shown in the accompanying table.

Mechanical analyses of type subsoils.

Diameter.	Conventional names.	276. Pine barrens.	284. Truck.	286. Tobacco.	290. Oriskany, "fine earth."	280. Wheat.	278. River terrace.	282. Triassic.	238. Catskill, "fine earth."	289. Shales, "fine earth."	288. Helderberg limestone.
mm.											
2–1	Fine gravel	*4.87	1.34	1.36	0.64	0.00	1.60	0.00	0.00	0.05	†1.34
1–.5	Coarse sand	9.15	8.24	2.13	0.81	0.42	1.51	0.23	0.11	0.16	0.33
.5–.25	Medium sand	38.37	34.77	7.78	3.50	1.81	4.15	1.29	0.42	0.80	1.08
.25–.1	Fine sand	33.28	19.94	16.57	23.97	8.59	4.84	4.03	2.63	2.01	1.02
.1–.05	Very fine sand	3.52	11.11	19.83	34.76	32.06	8.54	11.57	11.35	6.70	6.94
.05–.01	Silt	3.47	12.15	25.41	10.03	23.65	44.92	38.97	40.23	31.63	29.05
.01–.005	Fine silt	1.55	4.17	4.52	3.03	6.77	5.78	8.84	10.90	14.24	11.03
.005–.0001	Clay	3.75	7.45	17.95	20.30	22.85	25.85	32.70	33.32	39.36	43.44
	Total	97.96	99.17	95.55	97.04	95.85	97.19	97.63	98.96	94.91	94.23
Organic matter, water, loss		2.04	0.83	4.45	2.96	4.15	2.81	2.37	1.04	5.09	5.77

No.	Soil.	Clay.	Surface area. in 1 gm soil	Approximate number of grains per gram.
		Per cent.	*Sq. cm.*	
276	Pine barrens	3.75	496	1,692,000,000
284	Truck	7.45	971	3,266,000,000
286	Tobacco	17.95	2,102	8,258,000,000
290	Oriskany, "fine earth"	20.30	2,173	9,154,000,000
280	Wheat	22.85	2,602	10,358,000,000
278	River terrace	25.85	2,924	11,684,000,000
282	Triassic red sandstone	32.70	3,593	14,736,000,000
238	Catskill, "fine earth"	33.32	3,669	14,839,000,000
289	Shales (Hamilton, etc.), "fine earth"	39.36	4,411	18,295,000,000
288	Helderberg limestone	43.44	4,575	19,638,000,000
....	Trenton chazy limestone	53.02	5,574	24,653,000,000

* This includes 1.81 per cent. coarser than 2 millimeters.
† This includes 0.82 per cent. coarser than 2 millimeters.

The tables are substantially as published in the Fourth Annual Report of the Maryland Agricultural Experiment Station, except that it has been found that a sample containing a large percentage of clay had been accidentally introduced into the truck type, and so few localities were represented that this made a great difference. The present type of truck soil is from twenty-eight localities. This table includes all of the principal agricultural soils in southern and western Maryland, except the very important soil of the Trenton limestone formation, represented here by only a single sample, but it does not include any of the soils of the Eastern Shore or any of the soils of the crystalline rocks of the Piedmont Plateau in northern-central Maryland.

The soils thus arranged according to the amount of clay they contain and the approximate number of grains per gram, which gives the texture of the soil, are arranged in the order of their relative agricultural value.

The approximate extent of surface area, in square centimeters per gram, is given in detail in the accompanying table for a number of the soil types and the approximate number of grains per gram, to show the relative value of each of the separations.

Surface area (sq. cm.) per gram of subsoil.

Diameter.	Conventional names.	276. Pine barrens.	284. Truck.	286. Tobacco.	280. Wheat.	279. River terrace.	282. Triassic red sandstone.	288. Helderberg limestone.
mm.								
2–1	Fine gravel	0.5	0.2	0.2	0.0	0.2	0.0	0.1
1–.5	Coarse sand	2.8	2.5	0.7	0.1	0.5	0.1	0.1
.5–.25	Medium sand	23.6	21.2	4.9	1.1	2.6	1.0	0.7
.25–.1	Fine sand	43.9	26.0	22.4	11.6	6.4	5.3	1.4
.1–.05	Very fine sand	10.8	33.8	62.5	100.9	26.5	35.8	22.2
.05–.01	Silt	26.7	92.5	200.7	186.2	348.7	301.4	232.7
.01–.005	Fine silt	47.7	127.0	142.8	213.2	179.5	273.5	353.4
.005–.0001	Clay	339.8	667.3	1,668.0	2,089.0	2,360.0	2,976.0	3,965.0
	Total	495.8	970.5	2,102.2	2,602.1	2,924.4	3,593.1	4,575.3

Approximate number of grains per gram of subsoil.

Diameter.	Conventional names.	276. Pine barrens.	284. Truck.	286. Tobacco.	280. Wheat.
mm.					
2–1	Fine gravel	7	3	3	0
1–.5	Coarse sand	160	142	38	7
.5–.25	Medium sand	5,356	4,794	1,114	258
.25–.1	Fine sand	45,700	27,050	23,320	12,050
.1–.05	Very fine sand	61,380	191,500	354,500	571,200
.05–.01	Silt	945,900	3,270,000	7,101,000	6,588,000
.01–.005	Fine silt	27,030,000	71,830,000	80,790,000	120,700,000
.005–.0001	Clay	1,664,000,000	3,267,000,000	8,170,000,000	10,230,000,000
	Total	1,692,088,503	3,342,323,489	8,258,269,975	10,357,871,515

Diameter.	Conventional names.	278. River terrace.	282. Triassic red sandstone.	288. Helderberg limestone.
mm.				
2–1	Fine gravel	3	0	12
1–.5	Coarse sand	26	4	60
.5–.25	Medium sand	583	181	157
.25–.1	Fine sand	6,701	5,556	1,456
.1–.05	Very fine sand	150,200	202,600	125,900
.05–.01	Silt	12,340,000	10,670,000	8,231,000
.01–.005	Fine silt	101,600,000	154,900,000	199,900,000
.005–.0001	Clay	11,570,000,000	14,570,000,000	19,430,000,000
	Total	11,684,097,513	14,735,778,341	19,638,258,585

It will be seen from these tables that the clay group has a most important influence on the texture of the soil, as shown in these calculations. In the extent of surface area it is far ahead of the other separations, although the effect of the coarser grades is still quite apparent. In the approximate number of grains per gram, which, according to these views, determines the extent of subdivision of the empty space in the soil, the clay group has by far the greatest value, and this and the fine silt practically determine the real texture of the subsoils, provided the grains have the same mean arrangement. The reason for this is found in the extremely small size of the grains of clay, so that a percentage of clay means a vast number of soil grains and a very large extent of surface area.

Assuming the amount of empty space for these subsoils, as given, the relative rate of flow of water through a certain depth with a uniform water content (12 per cent.), is given in the accompanying table, as calculated by the formulæ already given.

No.	Soil.	Space.	Water-content.	Relative time.
		Per cent.	*Per cent.*	*Minutes.*
276	Pine barrens	40	12	8
284	Truck	45	12	16
286	Tobacco	50	12	33
290	Oriskany	50	12	35
280	Wheat	55	12	45
278	River Terrace	55	12	49
282	Triassic	55	12	56
238	Catskill	55	12	58
289	Shales (Hamilton, etc.)	60	12	81
288	Helderberg limestone	65	12	100

With this uniform water content, if an inch in depth of water passed through the Helderberg limestone in 100 minutes, it would take about 45 minutes for the same quantity of water to pass through the type of wheat land of southern Maryland. With the same rainfall, therefore, and the same amount of water falling on each of these soils, the water will pass down through the light lands much quicker than through the heavier soils, providing the soils are short of saturation.

Some time after a rain when the excess of water had passed down through the light lands, and the rate of movement was about the same in all of the soils, the water content of these lands would be about as given in the next table.

No.	Soil.	Space.	Water-content.	Relative time.
		Per cent.	*Per cent.*	*Minutes.*
276	Pine barrens	40	5.3	101
284	Truck	45	6.2	103
286	Tobacco	50	8.4	102
290	Oriskany	50	8.6	101
280	Wheat	55	9.4	100
278	River terrace	55	9.6	100
282	Triassic	55	10.0	101
238	Catskill	55	10.1	100
289	Shales (Hamilton, etc.)	60	11.2	100
288	Helderberg limestone	65	12.0	100

This would be approximately the relative amount of water found in each of these subsoils some time after a soaking rain, and it agrees very well with the few actual moisture determinations which have been made in these soils. There is little doubt that these values, based on purely theoretical considerations, will be sustained, in the main, by actual moisture determinations and that they will give an expression of the texture of the land. The mean arrangement of the grains in the undisturbed subsoil of these great formations is probably not very different, except in special cases, as in the impervious clays of the Potomac formation or for local conditions, and it is probable that the amount and condition of the organic matter in the undisturbed subsoil of these great soil areas are sensibly constant and that their effect will not greatly differ, except under artificial conditions of cultivation and manuring.

There are undoubtedly exceptions to this, as may be seen very plainly in the Potomac clays and in the shales in the western part of the state, but these exceptions are due to conditions which can be readily recognized and which, indeed, are made apparent by the departure of these soils from the conditions which have been assumed.

The relations of these soils to water as shown by these calculations, and as it is believed will be shown by actual moisture determinations, are as different as in the artificial conditions of greenhouse culture.

In greenhouse culture the development of the plant can be largely controlled by judicious watering. Water may be readily added or withheld from different classes of plants, or for different kinds of development as needed, and the whole art of greenhouse culture is in the judicious control of the temperature and the moisture of the soil. Different classes of plants undoubtedly require different treatment for their best development. In field culture water can not be so readily added or withheld for certain classes of plants or for certain kinds of development, but we find that under the same rainfall these different soil formations have such different relations to water that they are able in themselves to maintain very different conditions of moisture for the plants, quite as different as in the artificial conditions of greenhouse culture, so that the conditions in these different soil formations are best adapted to particular kinds of plants; and we have here, it would appear, the reason for the local distribution of plants under prevailing climatic conditions.

It may be suggested that if water can move through the light truck lands, containing 5 per cent. of moisture, in the time it moves through the heavier limestone soils, containing 12 per cent. of water, as shown in these calculations, that the light truck lands should be able to supply the wheat crop with sufficient water as readily as the heavier clay soil; but when water descends in the soil the forces pulling it down are surface tension and gravity. But where it has to be pulled up to the plant the only force to pull it up is the surface tension, and this has to act *against* gravity. There is much less water surface to contract in the light, sandy lands, so that if 100 pounds of water are needed by the wheat crop in a given time there will be very much less water surface to contract—that is, much less force to pull the weight of water up to the crop in the light land than in the heavier soil.

Another interesting problem is suggested here in the application of these principles to the study of the relation of the soils to water. If the empty space within the soils is completely filled with water, as in a perfectly saturated soil, the amount of space will be an important factor in the rate with which this water can be removed, and the light, sandy lands, having much less space and a much smaller capacity for water, may be slower than the heavier soils in draining off the excess. This is shown in the accompanying table, and may very likely account for the matter of very common experience that crops suffer more in excessively wet seasons in light lands than they do on heavier soils.

No.	Soil.	Space.	Water-content (saturation).	Relative time.
		Per cent.	*Per cent.*	*Minutes.*
276	Pine barrens	40	20.10	74
284	Truck	45	22.41	87
286	Tobacco	50	27.42	121
290	Oriskany	50	27.42	130
280	Wheat	55	31.55	109
278	River terrace	55	31.55	119
282	Triassic	55	31.55	137
238	Catskill	55	31.55	140
289	Shales (Hamilton, etc.)	60	36.14	123
288	Helderberg limestone	65	41.22	100

These calculations of the relative rate with which water will move within these different subsoils are based solely on the skeleton structure. The influence of the organic matter is not considered, and the soil grains are assumed to have the same mean arrangement. These two factors, the amount of organic matter and the arrangement of the soil grains, are probably nearly alike under the normal conditions which prevail in these great soil formations, as has already been pointed out, but if they have not the same effect in the different soils they will undoubtedly make the difference in the relations of these soils to the circulation of water still wider than the values we have assigned. Each of these factors requires a distinct line of investigation, and this is necessary to the practical use and application of this work.

If it is thought that not sufficient importance has been given to the chemical composition of the soils in this treatment of the subject, it must be remembered that if it is admitted that the judgment of the practical farmer of the value of his lands is based on the general appearance or texture of the land which determines the relation of the soil to water, then this factor is the controlling cause of plant growth and distribution, and is of first importance in the treatment and improvement of the land, and it is only through the study of the texture of the soil that the theory of fertilization will be made clear.

EFFECT OF FERTILIZERS ON THE TEXTURE OF THE SOIL.

In the improvement of a soil the question should be asked, how do the conditions differ from the best conditions for the kind of crop or the kind of development desired, and this question must be answered by the effects which are usually very apparent to the eye. The soil may be too dry or leachy, or it may be too retentive of moisture. This may be apparent to the eye in the texture of the soil, or it may be shown in the growth, vitality, and development of the plant.

Take the case of the soil from the sand hills of South Carolina, which has been referred to in a previous section. The growth of the plant is very small, but it puts on a large amount of fruit in proportion to the size of the plant and the amount of food material which has been stored up, and it ripens the crop quite early. Both of these latter qualities are very desirable. The size of the plant, however, shows that the soil is either not sufficiently retentive of moisture, or it is so very retentive and impervious that it can not supply the moisture fast enough for the needs of the plant. The texture of the soil shows that the soil is not sufficiently retentive of moisture, and that it is in this direction, rather than the other, that the trouble lies, and that to improve the condition of the land this soil must be made more retentive of moisture. On the other hand, the red land is rather too close and too retentive of moisture; it maintains such an abundant supply of water that the plants develop a very large amount of foliage and grow to a large size, and while they produce a large yield per acre of seed cotton, there is not nearly so much crop produced in proportion to the amount of food material stored up as with the crop on the sandy land. There is a tendency also for the crop to be late in maturing. It requires a careful diagnosis to determine what is the trouble with the land, just as a physician must be able to judge from the symptoms what is the cause of the trouble with the patient; and he must act on this for the improvement of the system.

In greenhouse culture, an experienced florist can tell from the development and appearance of the plant whether it has received the proper treatment; and so with field crops, from the appearance of the plant, the kind of development, the texture of the leaf, the vitality of the plant, and the diseases or insect ravages to which it is subjected, all are very plain indications of the conditions of the soil, and it is from these symptoms that one must judge of the cause of the trouble, and it is in this line that the improvement of the land must be worked out.

To change the physical condition and texture of a soil so as to make it more retentive of moisture, there are two possible lines of procedure which may be clearly recognized and defined. The soil grains may be pushed further apart, not necessarily so that the volume of empty space will be increased, but that the fine grains of clay shall be pushed further out from the larger grains of sand, so that the grains will have a more symmetrical arrangement within the soil, or, if the grains have already such an arrangement as to give the full value to the clay, this skeleton structure can be filled in with organic matter by precipitation of organic matter within the soil.

The first of these principles can be illustrated in the opposite effects of ammonia and lime on fine particles of clay suspended in a liquid. If a drop of the turbid liquid containing a trace of ammonia be placed under the cover glass of a microscope, the fine particles of clay suspended in the liquid can not come close together, or, if they do, they are repelled. If, on the other hand, a trace of lime is added to the turbid liquid, the fine particles of clay and silt gather together in light flocks, and can not only approach each other, but are held together by some force.

The effect of ammonia in rearranging the grains in the soil has already been referred to. It is very probable that the chemical composition of the soil moisture will determine the distance apart of these fine silt and clay particles, so that they may come closer together when some fertilizers are added to the soil, or be pushed apart when others are applied. These movements could readily take place in a soil containing only a moderate amount of moisture, for the film of water around the grains would be much thicker than the diameter of the grains of clay, so that the latter would be immersed in what would be, relatively, a liquid of some depth.

This matter can probably be made the subject of experimental verification, and, indeed, the apparatus has been ready here for some time to determine this point, whether two surfaces immersed in a liquid can come closer together under a constant weight when certain fertilizing materials are present than when others have been dissolved in the water. Measurements of this kind are to be made, as preliminary work to the study of the effect of fertilizers on the arrangement of the soil grains. Fertilizers are certainly known to have some such physical effect as this on the soil, although the cause has never been worked out in this detail, nor has the effect itself ever been considered much in soil investigations, in the effect it would have on the soil and crop.

The effect of organic matter in retarding the rate of flow and making the soil more retentive of moisture, is much more apparent than the rearrangement of the soil grains. If a filtered extract of stable manure is poured on to a soil contained in a glass tube, the organic matter will be precipitated in light, flocculent masses within the soil, and the liquid will run through quite colorless. If the coarse, sandy soil of the sand hill formation in South Carolina, or of the truck lands in Maryland, are to be improved, there is nothing so good as stable manure to apply to the land, especially if the soil is already quite deficient in organic matter, as is usually the case. If a quantity of such a soil be placed in a glass tube with a cloth tied over the under end, and a filtered extract of stable manure poured on the soil, the liquid will pass through quite colorless, and the rate of movement will get slower and slower until, if sufficient organic matter is used, the soil can be made quite impervious to water.

The precipitation of the organic matter from solution, and the segregation of the solid matter into light, flocculent masses, can be watched through a microscope focused against the side of the tube.

If coarse, sharp building sand is used, the organic solution may pass through unaffected, but if lime or some other fertilizing materials are added to the sand, the precipitation occurs as in a soil proper. If the lime is mixed with the upper inch of sand, this will assume the dark appearance of a soil resting on a light, sandy subsoil, with a sharp line of demarkation between them, so that in such a soil, naturally deficient in lime and iron compounds, an application of lime or of some similar substance which coagulates the organic matter would be necessary to bring out the full effect of the organic manuring. As a matter of fact, there is no soil which responds so readily to lime as these light, sandy lands, when sufficient organic matter is added,or is present, for the "lime to act on."

The lime precipitates the nitrogenous matter of the stable manure from solution, and in this case, at any rate, it is this coagulated nitrogenous matter which makes the soil more retentive of moisture, and it is this nitrogenous matter, alone, of all forms of organic matter, which is valued as a fertilizing material. There seems no reason to doubt that if the carbo-hydrates were readily precipitated from solution in these light, flocculent masses that they would have the same effect in retarding the rate of flow of water through soils and in making the soil more retentive of moisture, and that they would then have nearly the same agricultural value.

Many organic substances can be coagulated or precipitated from solution by lime or various alkaline or saline bodies, while others would not be affected by these, but would be coagulated by acids and a different class of material. With this view of the matter, therefore, it would not be expected that different forms of organic matter would have the same effect on the same soil, or that the same kind of organic matter would have the same effect on different soils. This view of the matter makes it evident why stable manure and lime have always been given a value out of all proportion to the amount of plant food which they contain, and why a comparatively small application of these and other fertilizing materials often has an effect on the crop out of all proportion to the plant food they contain.

Some experiments have been carried on to study this effect of fertilizers on the movement of water through soils, both in the laboratory and in the field. In the laboratory, 8-inch Argand lamp chimneys have been used, 2 inches in diameter. A subsoil containing 26 per cent. of clay has been used in most cases, and a depth of 6 inches with 50 per cent. by volume of empty space. In the field work the fertilizers were thoroughly mixed with the soil to a depth of 6 inches, and samples will be taken in the undisturbed subsoil from below this for the actual determination of the rate of flow of water several times during the growing season. The work has not progressed far enough to be discussed in detail in this report, but it is giving very interesting results, and showing a very marked effect of fertilizers on the relation of soils to water.

One interesting fact brought out in these laboratory experiments is that when successive quantities of water are passed through a soil in a tube the rate becomes slower and slower. In one case, with 47 per cent. by volume of empty space in the soil, the rate decreased from 57 minutes to 169 minutes when eight successive quantities, of 100 cubic centimeters of water each, had been passed through. Another time, with 50 per cent. by volume of empty space, the rate decreased from 36 minutes to 265 minutes when eighteen successive quantities, of 100 cubic centimeters of water each, had been passed through. When a filtered extract of stable manure was passed through a similar lot of soil the rate decreased to about 2,000 minutes after six successive quantities of the extract had passed through, and the rate became so slow that the work could not be carried further. Lime or muriate of potash when added to the soil alone had little effect on the rate of flow, but seemed to increase it a little. When lime was added to the soil and an extract of organic matter then passed through, the rate at first was slower than when the lime had not been added, but it did not decrease as rapidly when successive quantities of organic extract had been passed through, and lime, acid phosphate, and kainite seemed to prevent the very marked effect of the organic matter alone; so, while lime or some similar substance is necessary to bring out the effect of organic matter in a sharp building sand, still, in the presence of lime and in this soil containing 26 per cent of clay and presumably a considerable amount of iron compounds, the organic matter did not have nearly as much effect on the soil when lime was present as when it was applied alone. It would seem that there must be some such difference to explain the difference in the effect of lime on stiff, heavy clays, and on light, sandy soils.

Dried blood, dried tankage, dried fish, and cotton-seed meal all had a very marked effect in retarding the rate of flow. Ammonium sulphate decreased the rate, but not very much; nitrate of soda decreased the rate very remarkably, and made the soil almost impervious to water. This can hardly be due to a precipitation, as in the case of the organic matter, and must, probably, be due to a rearrangement of the soil grains, as in the case of ammonia.

These results are preliminary and are not sufficient for a detailed discussion, but they certainly point out a very remarkable effect of these fertilizing materials on the texture of the soils and the relation of soils to water, and point out a line of work which will be necessary for the interpretation of the results of plot experiments, and for working out the true theory of fertilization.

The soil appears to a casual observer as a coarse and inert mass, popularly known as "earth" or "dirt"; it seems hardly as though it could be affected by any simple change of conditions. It is, on the contrary, extremely sensitive to even unappreciable changes of conditions, and the relation of soils to water is so extremely sensitive that there is little wonder that the soil is often injured by injudicious treatment, but the wonder is that it is not more often ruined by the treatment it receives.

In this moisture work it is extremely difficult to fill the same tube twice over with a similar soil and the same amount of empty space, and have the flow of water agree closely, and this is the more difficult the heavier the soil is. If the soil is moistened before being loaded into the tube the rate of flow of water will be quicker up to a certain point with the amount of moisture the soil contained, showing that the grains had a different arrangement, and that the fine grains of clay were held more closely against the larger grains of sand.

The following results show this very plainly, the same kind of soil was used in all cases and contained about 26 per cent. of clay, the same tube was also used. Three hundred and fifty grams of soil were mixed with the requisite amount of moisture and loaded into the tube so that it should be 6 inches deep and contain 47.4 per cent. of empty space. The soil was then saturated and the rate of flow observed.

Grams.	Space.	Moisture.	Rate.
	Per cent.	*Per cent.*	*Minutes.*
350	47.4	0	128
350	47.4	2	65
350	47.4	3	60
350	47.4	4	45
350	47.4	6	36
350	47.4	8	27

There is a limit to this, of course, for when the soil contained too much water the grains were pushed out and the water went through much more slowly.

The rate of flow becomes much slower if the soil is left standing in the tube for a few days. Then, unless just the proper amount of empty space is left in the soil, the soil will either swell or contract when it is saturated with water. Even in the determinations of the flow in the soil in its natural condition in the field, if the sample is taken when the soil is dry it will often swell somewhat after it is imbedded in the paraffine and saturated with water.

These changes are extremely subtle and it is impossible, oftentimes, to detect any reason for the change.. The addition of pure water or of fertilizing material may often change the rate of flow to a very remarkable extent. This whole work indicates that instead of being an inert mass the soil is extremely sensitive to all changes of conditions and is full of life and movement.

If these forces can be directed and controlled they are amply sufficient to bring about any desired change in the arrangement of the soil grains, and of the texture of the soil, and it remains to find out how these conditions can be most successfully controlled, or how best to take advantage of them in the improvement of the land.

A METHOD FOR THE DETERMINATION OF MOISTURE IN THE SOIL.

It is extremely desirable that a method be devised for the determination of the moisture in the soil, without removing a sample from the field.

A method which has given promise of good results is based on the changing electrical resistance between two plates, permanently buried in the soil, with the changing moisture content. But it seems to be impossible to secure good contact between the soil and the plates.

The method, as first devised, consisted of burying alternate plates of zinc and copper in the soil, and reading the deflections of a galvanometer when contact was made between the zinc and the copper plates. The deflections were far greater when the soil was wet than when it was dry, but polarization took place so rapidly that satisfactory readings could not be taken.

After this, copper plates were buried some distance apart and a current sent across from one to the other and the resistance measured, but this also was unsatisfactory. Finally an induction coil was used, and a Wheatstone bridge arrangement, with a telephone instead of a galvanometer. Copper plates were at first used to bury in the soil, then carbon, and lastly mercury, contained in clay or in flat porous cells such as is used in batteries.

The plates are put so far apart that the resistance is about 1,000 ohms when the soil is in "good condition" or contains about 8 or 10 per cent. of water. As the soil dries the resistance increases up to

1,500 or 2,000 ohms, and when it is saturated, after long continued rains, the resistance falls to about 200 ohms. The resistance regularly falls with increasing temperature, but the effect is far greater than for any known temperature coefficient.

When the plates are inclosed in sealed jars so that the water content remains constant, the resistance is constant for any temperature, even after the plates have remained undisturbed for a year or more. When the water content changes, however, the resistance gradually increases, so that when the soil is repeatedly wet and dried the resistance becomes much higher for any given condition of temperature and moisture.

It appears that the soil moves away from the surface of these foreign bodies. The soil presses against the plates with increasing temperature, and, the contact being better, the resistance is lower; as the temperature falls, however, the soil is withdrawn and the resistance rises. With changing moisture content the soil gradually compacts within itself and pulls away from the plates, and the resistance gradually increases.

In pot culture where the soil is contained in glass jars the soil becomes more compact and pulls away from the glass sides of the jar, leaving a considerable space between the soil and the sides of the jar. This is not so noticeable with porous earthenware pots, so it was thought that possibly the form or nature of the surface of the foreign body had something to do with this movement, and it was for this reason that carbon plates were substituted for copper. Such plates have been buried now for a year, and the resistance does not seem to have permanently increased, but every day the resistance rises and falls with changing temperature, as will be shown in the accompanying table.

It was thought that this movement might only occur at the surface of the foreign body, and it was attempted to imbed these carbon plates in clay and burn them in a porous tile. This could not readily be done, however, and then mercury was tried; first, by moulding a form of a plate in the soil, in moulding sand, or in clay, but much trouble was found in the liquid filtering down into the soil. The mercury was then put into flat, porous cells, and these were buried in the soil, but these also show the effect of changing temperature. As it has been shown in another way that the soil actually moves away from these foreign bodies and that this movement may continue for a long time, if the movement is followed up, it is evident that the mercury would give no better results if put directly in the soil than the carbon plates have given. There was this advantage in using the mercury instead of a rigid plate, that the mercury would follow the movement of the soil and maintain good contact. We have found, however, that with any yielding substance of this kind the movement would continue, and the indications are that the soil would contract or move away indefinitely from the foreign substance.

There seems to be no way to overcome this difficulty or to secure good contact with the soil, and it seems as though for this reason the method could not be perfected, but the indications it has given of this movement in the soil are of very great interest and value, and perhaps quite as important as the method itself would have been.

The accompanying table gives the readings for about three months of a series of carbon plates which were buried in the soil about a year before these readings were taken. There are three plates connected together on each side, each plate being 3 by 12 inches, and the two sets of plates were buried about 18 inches apart, the top of the plates being two inches below the surface of the ground. Rather more than the average amount of rain fell during this time and the soil has been unusually moist. During a prolonged drought the resistance of these plates would probably go up to 1,500 or 2,000 ohms.

Actual determinations have been made for part of the time of the amount of moisture in the soil, and the temperature of the soil as well as the principal meteorological conditions, but these are not given as they are hardly necessary in the present stage of the work. The important point to be worked out first is to secure the proper contact between the soil and plates and to overcome the extreme sensitiveness of this system to the natural movements within the soil.

Electrical resistance of the soil in ohms.

Date.	April.			May.			June.		
	8 a. m.	1 p. m.	8 p. m.	8 a. m.	1 p. m.	8 p. m.	8 a. m.	1 p. m.	8 p. m.
1	....	....	....	280	260	305	165	170	220
2	....	....	....	330	315	355	227	227	285
3	....	....	....	345	335	380	270	245	280
4	....	....	....	400	355	337	285	255	265
5	....	....	....	387	365	440	250	255	200
6	....	....	....	462	407	377	200	220	255
7	....	....	....	417	395	500	270	255	270
8	....	....	....	535	450	530	265	200	158
9	....	....	....	....	450	520	160	....	....
10	....	....	....	605	485	499	140	140	145
11	....	....	....	300	260	245	155	150	180
12	510	430	510	255	255	301	180	160	200
13	595	470	539	309	280	325	200	200	200
14	595	500	350	320	310	....	255	235	265
15	310	265	265	185	180	150	290	....	....
16	320	270	325	160	155	185	300	295	295
17	300	285	300	200	190	210	335	315	285
18	270	257	240	245	220	225	295	275	....
19	255	200	250	220	160	155	270	270	300
20	260	250	244	170	150	167	300	....	260
21	220	220	220	160	160	....	290	280	300
22	220	200	200	160	....	165	315	305	330
23	210	195	210	170	160	182	....	180	200
24	200	190	205	200	175	203	220	215	....
25	235	225	245	220	195	234	150	....	175
26	250	220	267	245	225	175	200	200	230
27	285	245	300	155	150	165	220	220	135
28	330	315	340	175	149	160	135	135	149
29	315	265	250	175	170	175	150	150	151
30	265	220	270	175	160	150	178	125	....
31	....	....	....	155	160	165	....	....	....

A MOVEMENT OF SOIL GRAINS.

As it seemed probable from the variations in the electrical resistance of the soil that there was a movement of the soil grains this matter was made the subject of experimental investigation.

A thin rubber ice bag with a capacity of, approximately, 1,000 cubic centimeters, was securely fastened to a rubber stopper bearing a 60 cubic centimeter separating funnel for the admission of water, and a small tube, with an internal diameter of about 3 millimeters, which projected about 2 inches above the surface of the ground, and was then bent horizontally for about 18 inches in length, and was graduated the whole extent into eighths of an inch.

The rubber bag was about one-third filled with water and buried in the soil, the soil being pressed around the bag so as to force the water up into the small tube. The tube being horizontal maintained a constant pressure whether the bag expanded or contracted, and when the water fell in the tube, as it did almost every day, water was added through the separating funnel. This arrangement insured a constant pressure in the bag, and if there was any tendency for the soil to move away the bag would expand and follow it. The bag was buried in about 200 pounds of soil contained in a large tub and was kept in one corner of the laboratory in the house in Clifton, which is very solidly constructed. The soil was a mixture such as would be used in greenhouse work. There was no convenient way of determining the quantity of water in the soil, so it was watered from time to time and was kept in a fair condition for a growing plant.

This apparatus has been standing for nearly 4 months, and nearly every day water has to be added through the separating funnel to bring the level in the tube to the zero mark. It is set every morning, and, as a rule, the water gradually rises during the day and begins to fall in the afternoon and continues to fall during the night.

The movement is not constant, but seems to depend on meterological conditions. During a long rainy spell the water in the tube is generally beyond the zero point, and often during such periods it remains beyond the zero point for several days at a time; when the weather clears, and especially when there is a sudden change to clear, cold weather, the liquid falls in the tube very rapidly. Indeed, this movement is so extremely sensitive that it is frequently noticed that a change to stormy or fair weather could usually be depended on by the indications of this movement, often a day or two in advance of the actual change; that is, when the level of the liquid in the tube was over the zero mark persistently in fair weather, dull, rainy weather would nearly always follow within a day or two. On the other hand, in continued dull, rainy weather, with no apparent signs of clearing, the level of the liquid in the tube would very often begin to fall perhaps a day or two before the actual change occurred.

It was believed that these changes were dependent upon meteorological conditions, and there were indications both here and in the variation of the electrical resistance of the soil which seemed to show that this movement was largely dependent upon the changing atmospheric pressure as well, of course, as upon changing temperature. There seems to be no very simple relation, however, between the movement of the soil grains and the readings of the ordinary meteorological instruments, but still there does seem to be a relation between the movement of these soil grains and climatic changes.

One source of error which would hide any such close relation is in the extreme sensitiveness of the apparatus. At first, at any rate, before the soil became very compact in the tub, any one walking across the floor in the vicinity of the tub, or the least touch of a finger on the side of the tub, or a clap of thunder that would jar the tub, could be plainly recognized in their effect in the fall of the liquid in the tube. After the first few days the effect of this was hardly appreciable, but still it is impossible to say what effect they continued to have. A similar arrangement was buried in the soil of the field when this work was first started in South Carolina, but this was found also to be so extremely sensitive as to be affected by a footstep even a considerable distance away. The level of the liquid in the tube would rise and fall with the pressure of the foot on the ground.

When the apparatus was first set up the level of the liquid fell very rapidly whenever water was added to the soil, and it was believed that the repeated changes in moisture content was really the principal cause of the movement. As the soil became more compact, however, it was found that water could be added to the soil without materially affecting the level of the liquid in the tube. This was rather unexpected, as the movement still continued from other causes.

Fearing that the rubber sack which had been used in this instrument was rather thin, and that water was liable to get through the sides in one way or another, some other bags were made to order out of heavy, pure rubber cloth. The bags have a capacity of about 500 cubic centimeters, and were tested for several days, as was the other, in fact, before being set up. This apparatus was put into a very large, wide-mouthed glass packing bottle, and was put down in the basement, on a wide stone window-sill, where it was supposed it would be perfectly free from jar or disturbance of any kind, as the walls of the building are about two feet thick.

The jar is fitted with a manometer, and arranged so that the temperature or pressure can be varied at will, to study the effect of these conditions on the movement. The soil was put in air-dry, being pressed around the bag as before until the liquid rose into the tube.

The apparatus has been set up for very nearly two months, and the soil has not been watered during this time. The movement, however, goes on in this air-dry soil and the water is constantly falling in the tube as the soil compacts within itself and the bag expands. The level in the tube regularly rises every day above the zero point, and falls in the afternoon and night. But the total fall is greater than the rise, and water has to be added through the separating funnel to bring the liquid in the tube to the zero point. It must be remembered that the rise and fall of the water in the tube here referred to is not a vertical rise and fall which would vary the pressure, but is a horizontal flow, so that the pressure in the bag is constant.

This movement in the dry soil will be watched for a considerable time before water is added to the soil or the conditions are changed in any way, for it is a matter of very great interest. Similar apparatus will be planted out in the field, and the effect of stirring the soil or of cultivation will be studied.

This rubber bag, while flexible and adapting itself to marked changes of the soil, still can not follow any detailed movement as a growing root could, or develop in the line of greatest movement and of least resistance, but the whole side of a bag, or a large area, must move together, and this movement will depend upon the smallest movement of the soil grains. It seems certain, however, that the soil is moving away from these rubber bags, and the bags themselves, under a constant pressure from within, are slowly enlarging, and that the same forces that cause this movement may act in the development of roots through the soil, so that it would not be necessary to conceive of a root forcing its own way through the hard subsoil, as the soil itself will materially aid this development by a movement away from the surface of the root. This movement of the soil grains must have an important bearing on the development of roots through the soil, and the nature of the root surface and the matter which it exudes may have an important effect on the movement itself.

The accompanying table gives the readings of the apparatus in the soil in the tub for three months, with the temperature of the soil, and the very complete meteorological data for March from the records of the Weather Bureau observer in Baltimore. The meteorological instruments are located about 2½ miles in an air-line from Clifton, so that the results can not be as directly applied as though the observations were taken closer. The readings of the instrument are given in eighths of an inch, which was the graduation of the tube, and the last column gives the daily rise or fall in the tube in inches. The instrument was set at 8 a. m. each day by letting in water through the separating funnel to bring the water in the tube to the zero mark, but when the water was already beyond this point the instrument was not set.

Readings of the apparatus for three months.

Date.	Temperature of soil (degrees F.).			Reading of instrument.			Rise or fall (inches).
	8 a. m.	1 p. m.	8 p. m.	8 a. m.	1 p. m.	8 p. m.	8 a. m. to 8 a. m.
March 1	59	....	....	0	....	− 1	− 1.37
2	60	62	59	− 5	− 3	....	− 1.00
3	59	60	....	−22	− 4	....	− 3.25
4	59	62	64	−17	− 6	−10	− 2.00
5	64	64	64	− 7	− 5	− 2	− 1.47
6	59	59	60	−78	+ 2	+ 2	− 12.00
7	57	60	62	−23	− 1	+11	− 2.90
8	61	62	64	+ 7	+ 3	+ 4	+ 0.87
9	62	64	65	−10	− 1	+ 1	− 2.12
10	63	65	66	−13	− 3	− 9	− 1.62
11	60	61	64	−71	− 1	− 2	− 8.87
12	57	60	62	−20	− 4	− 3	− 2.50
13	59	59	58	− 9	− 11	−24	− 1.12
14	57	58	58	−43	− 2	− 3	− 5.33
15	57	59	60	−16	0	+ 6	− 2.00
16	57	61	61	+23	+ 20	+19	+ 3.62
17	57	61	62	+10	+ 4	+12	− 1.62
18	55	58	56	− 1	− 14	*	− 1.37
19	55	58	59	....	....	−10	− 59.00
20	55	56	58	−78	+ 2	+ 2	− 12.00
21	55	58	59	−30	− 8	−15	− 3.75
22	53	59	61	−32	− 4	−10	− 4.00
23	59	62	65	+ 7	+ 5	+15	+ 0.85
24	61	63	64	− 7	− 7	+ 2	− 1.75
25	62	64	66	−13	−136*	− 1	− 1.62
26	62	63	64	−13	− 7	−26	− 18.36
27	62	62	61	−52	− 8	−27	− 6.50
28	58	61	64	−55	− 12	− 2	− 6.90
29	61	62	63	−17	− 5	− 4	− 2.13
30	60	63	66	−23	3	+11	− 2.87
31	62	64	64	− 9	− 5	−10	− 1.12
Mean	58.6	61	62	....	....	....	− 5.32
Total fall	....	....	....		(24.75 cc.)		−165.00

Date.	Temperature of soil (degrees F.).			Reading of instrument.			Rise or fall (inches).
	8 a. m.	1 p. m.	8 p. m.	8 a. m.	1 p. m.	8 p. m.	8 a. m. to 8 a. m.
April 1	62	65	67	−26	− 1	0	− 3.25
2	66	67	68	− 1	−17*	−29	− 0.12
3	69	71	71	−38	+ 1	+11	− 4.75
4	71	71	71	+ 1	−17	−14	+ 1.25
5	70	70	71	−82	− 2	− 6	−10.25
6	70	70	67	−34	− 7	−13	− 4.25
7	66	68	67	−84	+ 3	+ 3	−10.50
8	64	66	66	−26	+ 1	+ 1	− 3.25
9	62	63	60	−20	− 7	−24	− 2.50
10	55	55	55	−55	− 6	−11	− 7.00
11	53	56	59	−68	− 1	+ 6	− 8.40
12	57	59	62	+10	+ 2	+10	+ 1.25
13	59	60	58	+ 7	+ 4	+ 4	+ 0.37
14	59	62	64	0*	0	− 1	− 0.87
15	58	61	61	−15	− 7	− 1	− 1.87
16	58	61	62	−23	− 1	+ 5	− 2.87
17	59	60	60	−12	0	0	− 1.50
18	58	62	67	−25	− 7	− 4	− 3.12
19	63	66	66	−17	− 1	+ 9	− 2.12
20	63	64	64	− 6	0	+ 3	− 0.75
21	63	64	64	− 7	− 3	− 5	− 0.93
22	61	64	65	−17	0	+ 4	− 2.12
23	63	68	65	− 4	− 1	+10	− 0.50
24	64	67	67	−12	+ 3	+11	− 1.50
25	64	65	64	− 5	− 6	− 5	− 0.62
26	62	63	63	−19	0	+ 2	− 2.37
27	60	63	65	−11	+ 1	+ 9	− 1.37
28	63	66	67	+12	+11	+18	+ 1.50
29	60	67	69	+19	+16	+15	+ 2.37
30	66	66	65	+ 1	− 1	0	− 2.25
Mean	62.4	64.3	64.6	....	....	....	− 2.35
Total fall	....	....	....		(10.58 cc.)		−70.59

*Added water to soil.

Readings of the apparatus for three months—Continued.

Date.	Temperature of soil (degrees F.).			Reading of instrument.			Rise or fall (inches).
	8 a.m.	1 p.m.	8 p.m.	8 a.m.	1 p.m.	8 p.m.	8 a.m. to 8 a.m.
May 1	63	65	65	−16	0	+7	−2.00
2	65	69	70	+3	+6	+17	+3.70
3	68	72	73	+13	+17	+19	+1.25
4	68	69	71	+18	−5	+9	+0.62
5	68	69	69	−1	−3	−8	−2.12
6	67	69	71	−80	+4	+10	−10.00
7	67	68	65	−7	−5	−4	−0.87
8	62	63	62	−26	−1	−3	−3.25
9	....	64	63	....	−20	+7	−2.50
10	62	63	63	−4	0	+4	−0.50
11	63	65	66	−4	−2	+3	−0.50
12	65	64	65	−3	−3	−6	−0.37
13	64	65	65	−20	+1	+8	−2.50
14	63	64	....	−7	−4	....	−0.87
15	64	65	66	−16	+3	+7	−2.00
16	66	69	70	+9	−16	+26	+1.12
17	69	69	69	+21	+21	+26	+1.50
18	67	69	68	+18	+17	+19	−0.27
19	68	69	68	+21	+21	+12	+0.27
20	66	68	60	0	+2	+6	−2.62
21	64	65	....	−6	−9	....	−0.75
22	62	....	61	−24	....	+3	−3.00
23	62	63	62	−3	+2	+4	−0.27
24	62	63	63	0	−1	+3	0.00
25	64	65	66	+2	+4	+10	+0.25
26	66	68	69	+12	+14	+22	+1.25
27	68	66	66	+18*	+26	+26	+0.75
28	63	63	63	+14	+14	+16	−0.50
29	64	65	66	+2	+3	+1	−1.50
30	66	68	70	−14	0	+2	−2.00
31	69	71	72	−24	+1	0	−3.00
Mean	65.1	66.5	66.4	....	....	....	−0.97
Total fall	....	....	....		(4.54 cc.)		−30.28

* Added water to soil.

Meteorological data from the station at Baltimore for March, 1892.

Date.	Pressure.			Temperature.					Relative humidity.			Absolute humidity, grains per cubic foot.		
	8 a.m.	8 p.m.	Mean.	8 a.m.	8 p.m.	Max.	Min.	Mean.	8 a.m.	8 p.m.	Mean.	8 a.m.	8 p.m.	Mean.
	Inches.	Inches.	Inches.	°	°	°	°	°	Pr.ct.	Pr.ct.	Pr.ct.			
1	29.80	29.97	29.88	35.1	34.0	37	34	36	99	95	97	2.379	2.126	2.252
2	30.09	30.22	30.16	29.5	31.0	32	30	31	90	90	90	1.674	1.817	1.746
3	30.15	30.06	30.10	31.0	38.0	43	28	36	74	62	68	1.476	1.674	1.575
4	30.01	29.86	29.94	38.5	48.0	55	35	45	52	66	59	1.415	2.563	1.989
5	29.85	29.87	29.86	41.1	34.5	42	34	38	88	86	87	2.563	1.969	2.266
6	30.00	29.96	29.98	34.0	41.0	46	32	39	67	53	60	1.540	1.606	1.573
7	30.00	29.92	29.96	37.5	46.0	57	34	46	66	65	66	1.745	2.379	2.062
8	29.61	29.32	29.46	39.5	44.0	47	39	43	96	96	96	2.659	3.189	2.924
9	29.44	29.61	29.52	41.0	50.0	54	38	46	100	55	78	2.967	2.292	2.630
10	29.66	29.73	29.70	41.5	33.0	50	33	42	96	80	88	2.862	1.817	2.340
11	29.92	30.02	29.97	21.0	28.5	32	20	26	59	62	60	.806	1.138	.972
12	30.00	29.88	29.94	29.0	49.5	61	25	43	57	52	54	1.090	2.126	1.610
13	30.03	30.07	30.05	35.0	31.0	36	30	33	72	95	84	1.745	1.892	1.818
14	30.30	30.31	30.30	24.0	29.0	34	24	29	50	78	64	.772	1.476	1.124
15	30.41	30.34	30.38	25.9	33.5	35	25	30	53	58	56	.878	1.298	1.088
16	30.40	30.33	30.36	22.8	29.5	31	23	27	93	68	80	1.355	1.298	1.326
17	30.38	30.15	30.26	25.0	25.0	27	24	26	63	100	82	.999	1.606	1.302
18	29.82	29.69	29.76	27.3	30.0	31	24	28	89	84	86	1.540	1.606	1.573
19	29.91	29.90	29.90	24.1	34.5	39	23	31	62	58	60	.957	1.415	1.186
20	30.17	30.30	30.24	29.1	34.0	38	29	34	62	53	58	1.190	1.243	1.216
21	30.53	30.52	30.52	22.0	31.0	34	21	28	60	54	57	.841	1.090	.966
22	30.54	30.31	30.42	26.5	37.0	38	23	30	72	74	73	1.190	1.892	1.541
23	30.03	29.98	30.00	41.5	51.0	65	37	51	92	62	77	2.862	2.659	2.701
24	30.24	30.15	30.20	38.0	42.0	50	35	42	53	69	61	1.415	2.208	1.812
25	30.17	30.05	30.11	41.5	50.0	56	34	45	71	55	62	2.208	2.292	2.250
26	29.94	29.75	29.84	44.0	44.0	48	43	46	78	100	89	2.563	3.306	2.934
27	29.46	29.65	29.56	44.0	39.0	44	39	42	100	96	98	3.306	2.659	2.982
28	29.95	30.09	30.02	40.8	44.0	50	39	44	68	63	66	2.046	2.120	2.086
29	30.29	30.26	30.28	39.9	43.0	53	36	44	52	74	63	1.540	2.379	1.460
30	30.33	30.23	30.28	37.9	44.5	47	35	41	42	52	47	1.138	1.817	1.479
31	30.26	30.37	30.32	39.6	40.0	42	39	40	90	100	95	2.563	2.862	2.712

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MARYLAND AGRICULTURAL

EXPERIMENT STATION.

REPORTS OF

THE DIRECTOR AND THE PHYSICIST.

SOIL INVESTIGATIONS.

BY PROF. MILTON WHITNEY.

JANUARY, 1892.

FOURTH ANNUAL REPORT

OF THE

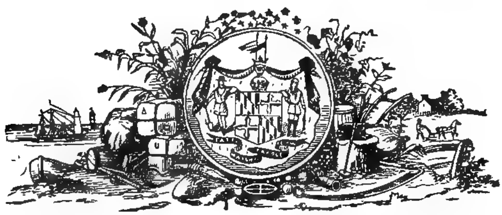
MARYLAND AGRICULTURAL EXPERIMENT STATION,

AT THE

AGRICULTURAL COLLEGE,

COLLEGE PARK,

PRINCE GEORGE'S CO., MARYLAND.



1891.

ANNAPOLIS:
C. H. BAUGHMAN & CO.,
STATE PRINTERS.
1892.

ORGANIZATION

OF THE

Maryland Agricultural Experiment Station.

CORPORATION:

The BOARD OF TRUSTEES of the MARYLAND AGRICULTURAL COLLEGE.

Agricultural (Station) Committee of the Board of Trustees:

Ex-officio, Hon. E. E. Jackson, Governor, *President of the Board.*
Messrs. Goldsborough, Seibert, Silver, Brattan and Biedler.

OFFICERS AND STAFF:

Henry E. Alvord, C. E., *Director.*
Harry J. Patterson, B. S., *Chemist.*
Albert I. Hayward, B. S., *Agriculturist.*
Thos. L. Brunk, B. S., *Horticulturist.*
Milton Whitney, M. Sc., *Physicist.*
Ernest H. Brinkley, *Machinist.*
David B. Perry, *Stenographer.*
Jos. R. Owens, M. D., *Treasurer.*

LOCATION.

On the Estate of the Maryland Agricultural College, in Prince George's County, eight miles north from the City of Washington.

Railroad Station, for Passengers and Freight: College Station, Md. (On the Baltimore & Ohio R. R.)

P. O.—College Park, Prince George's Co., Maryland.

Telegraph Address.—College, Md. (Western Union Tel. Co.)

Express Office.—College Station, Md. (United States Express Co.)

☞ *Address, in all cases—*

MD. AGR'L EXPERIMENT STATION.

FOURTH ANNUAL REPORT

OF THE

MARYLAND AGRICULTURAL EXPERIMENT STATION,

FOR THE YEAR 1891.

REPORT OF THE DIRECTOR.

The past year has been the busiest one which the Station has had. More work has been done, and of greater variety, than heretofore. In order to give "a full and detailed report of its operations," as required by law, the printed record must be extended beyond the limits of previous years. As time passes the facilities for work become more complete. The land is brought into a more satisfactory condition; trees grow and perennial plants become established; buildings are extended; appliances are increased, and the equipment generally is improved. Thus far, we have been able each year, to expend less time and money upon preparation, and more for labor and the current expenses of experimentation, than the year before. The time will soon come when, with our fixed income, it will be impossible to materially increase the quantity or the variety of the work; the question will then be, how, in what directions, and upon what subjects, the resources at our command can be best applied, year by year.

THE SEASON:—As heretofore, it is necessary to first report upon the weather, in order that the climatic conditions may be understood, which have applied to the field-work of the Station, during the year.

The season of 1891 has here differed from the normal mainly in its "precipitation" or rainfall. The quantity and distribution of the rainfall is the prime factor in the climatology of this latitude, as regards the agricultural interests of the year. The figures following compare the past season, in this respect, with the two next preceding, and show it to have been a year of excessive rainfall.

Years:	1891.	1890.	1889.	Normal,
Rainfall in Inches:	50.55	36.29	59.59	44.+
Number of Rainy Days:	128.	151.	135.	?

By comparing the depth of rainfall with the number of rainy days, it is apparent that the year 1890 was one of less than an average quantity of rain well distributed, while in 1891, as well as in 1889, there was excessive rainfall concentrated in comparatively few days, or heavy rains. With forty per cent. more rainfall than the year before, and all of this excess during the first seven months of the year, it will be readily understood that field-work was much interrupted and retarded. Yet May was a dry month, too dry for grass, cutting short the hay crop, but favorable for grain. The late summer and autumn months, on the other hand, were rather dry and fair, without being too warm, and exceptionally fine for ripening corn and for most farm work. The general facts, as recorded in different parts of the State, are shown by the following table of yearly averages:

Place of Record.	Temperature.		Rainfall, including Snow.		
	Normal Mean.	Mean of 1891.	Normal in Inches.	In 1891, Inches.	Rainy Days. No of in 1891.
College Park, Md.......	54.-?	54.31	44.--?	50.55	128.
Washington, D. C......	54.8	55.35	44.44	52.54	138.
Baltimore, Md..... ...	53.1	55.60	44.34	54.21	143.
Cumberland, Md.......	51.8	53.35	33.19	46.25	96.
Wicomico Co., Md.. ...	...	55.7	....	56.17	...

Detailed records of the observations at this Station (recorded as College Park) are given in tables appended to this report. The other records, which afford an interesting comparison, have been courteously supplied by the Weather Bureau at Washington and the Maryland State Weather Service.

It appears that at all points reported, the mean or average temperature for the year was rather lower than for 1890. This applied to every month in the year except April, which was warmer than usual, and December, which averaged 9 degrees warmer than the year before, although cooler by 2 degrees than the same month in 1889. In other words, the Summer was cool and the Winter was mild. The mean temperature for 1891 at this Station was 1½ degrees lower than the year before. As noted last year, the mean temperature at the Station seems to range about one degree less than at the cities of Baltimore and Washington. In Wicomico county the record closely agrees with Baltimore, and at Cumberland, as usual, it was considerably cooler.

In the rainfall record some of the same features are seen as last year. We had less rainfall by two to four inches, and fewer rainy days by ten to fifteen, than in the cities on either side of us. The rainfall of the year, within this State, appears to have increased from West to East. Of the places above reported, Cumberland had the least this year, instead of the most, as in 1890. But after all, as is elsewhere shown in this Report, the quantity of rain which falls upon the soil, and even its distribution, concerns us far less, agriculturally, than the question of how it moves after entering the soil, and what we can do to control this movement and measurably regulate the supply of moisture for our crops.

Co-operation:—Less has been done than in years previous, in co-operative work with other Stations, and less than is believed to be economical and judicious. For the best results from this national system of Experiment Stations, there should be more co operation and co-ordination in the work of the Stations in the several States, and this should be required by law, to a reasonable extent, if it does not come about naturally and voluntarily. In the work of this Station, within the State, co-operative effort has been necessary, and willing and efficient helpers have been found, as later mentioned in appropriate places.

Scientific Expedition to Southern Maryland:—Several lines of proposed work made a preliminary visit to Southern Maryland expedient, early in the year. A party was organized, including representatives of the United States Topographical and Geological Surveys, the Johns Hopkins University and this Station, with several visiting scientists from other States. Upon application, the Board of Public Works considerately granted the use of the Steamer Gov'r Thomas, and an attending schooner, from the State Fishery Force, after the close of the season of police patrol, and thus provided suitable transportation and quarters. The party paid for all labor and provisions incident to the trip. The expedition took place in May, starting from Baltimore and ending at Washington. The Western shore of Chesapeake Bay was closely examined, as well as the Patuxent river, as far as navigable, and the Maryland side of the Potomac; frequent excursions were made inland, as far as circumstances permitted. The subjects studied by different members of the party included the topography, geology and soils of the region, its vegetation and staple crops, the marl deposits and the oyster beds. Much of the work of this Station for the year, connected with tobacco, marls and soil studies, was laid out at this time.

The expedition was pronounced a success by all concerned, and it suggests a way in which portions of the State Fishery Force can be profitably used at times, when not otherwise needed, to assist in promoting the material welfare of the State, and without additional public expense.

THE JOHNS HOPKINS UNIVERSITY:—This great university has constantly shown its earnest wish to co-operate with the Station in any work tending to develop the natural resources of the State. This is evidenced by the share it has taken in the expedition above mentioned, and in the State Weather Service, the Map of Maryland and the Soil Investigations, as briefly acknowledged in the Report of the Maryland Agricultural College for 1891. President Gilman has not only responded cordially to every suggestion made, and been effectively supported by the Board of Trustees,—but offers of assistance have been made far beyond what could have been asked. Some of the important work of the Station would have been impossible, at least for some years to come, but for this substantial aid. This has been shown especially in connection with the Soil Investigations conducted by Professor Whitney. In arranging for this work, it became evident that its success depended upon being so situated, at the outset, as to have available fully equipped laboratories and libraries, and the personal help of eminent investigators, in solving such purely scientific problems in chemistry, geology and physics, as might arise in the progress of the investigations. All these facilities were freely offered by the University, and it was manifestly expedient, if not necessary, to locate the work in Baltimore. Rooms were at first placed at our disposal in the geological building of the University, but the work soon outgrew those limited accommodations, and the

University Trustees then gave the use of the Hopkins Mansion at Clifton, on the Harford Road, and all desired privileges upon the entire estate. This comprises over four hundred acres of park, woodland, arable fields, gardens, orchards and green-houses, all well kept and offering ample facilities for the observation and study of soils, under varied conditions, with and without crops. The mansion furnishes admirable accommodations for laboratories, office and quarters for the workers, thus concentrating the work of this division of the Station. Clifton is within three miles of the centre of the city, directly upon a horse-railway line, and thus having easy communication with all parts of the State. This generous action on the part of the University, as well as the lively interest and cordial support evinced by all its officers, calls for especial praise and appreciative acknowledgment.

Soil Investigations:—In the last Annual Report of the Station, it was stated that an effort was about to be made to institute a systematic study of the agricultural soils of Maryland, with a view to their classification, description, defining the boundaries of typical formations and explaining local variations. The Station was soon after fortunate in securing the services of a competent person to undertake the work; this was the first essential step. The reasons for locating this branch of our Station work at Baltimore, and the particularly favorable auspices under which it has been there begun, have been already described. The preliminary report upon the first year's progress in these investigations, will be found at page 249, and to it attention is particularly invited.

A knowledge of the soil we cultivate, with its characteristics, changes, condition and capabilities, veritably lies at the foundation of all agricultural progress. It is not rational to grope about blindly and try hap-hazard experiments, with a view to improving a worn and apparently impoverished soil, without knowing something more than the single fact that it is unproductive. The true causes of its condition, or deterioration, and accurate information as to the difference between it and a soil satisfactorily productive, seem essential to intelligent and successful treatment. But in this all-important field, science has thus far done little for the practical benefit of the farmer. There have been few workers anywhere in this line, and especially in America. It is, however, too important a branch of agricultural research to be longer neglected. This Station takes pride in being the first to establish a division and assign a staff-officer exclusively to soil investigations, and in commencing the work, with such strong allies and under such auspicious circumstances.

It will be seen from the following report, that the subject has been approached upon a line which is in the main new, at least for this country. The present presentation of the work must be understood as preliminary and subject to the modifications and changes which may result from further investigations. But the work already accomplished has developed indications which, if verified by subsequent research, will establish truths of great importance and far-reaching in the application of science to the treatment and cultivation of the soil. As thus presented, the subject cannot fail to command the attention of students of agriculture,—and will probably call forth criticism. The latter is desired and invited. The officers of this Station wish to receive the opinions of fellow-workers everywhere, as to this soil investigation as thus far reported, and their views and suggestions as to its further prosecution.

Professor Whitney's report is also commended to the attention of every practical farmer and owner of agricultural land who may have the opportunity to read it. New things develop new ideas and necessitate new names and phrases. If parts of this report are found to require not only careful reading, but actual study, to be well understood, the extra mental effort will do no harm, and it is believed it will be well repaid. It must be remembered that this is preliminary work. Methods of investigation have to be first studied and justified. The first steps have been recorded as concisely and clearly as possible, although necessarily dealing with subjects and using terms which will be unfamiliar to many readers. The soil samples which are brought into use in these early stages of the work, are limited and represent only part of the State; this could not be otherwise. But as the work proceeds and later reports are made, the subject will become more familiar,—its processes and conclusions will be plainer. As time passes the investigation will embrace wider areas and more local questions,—and the application of its results will become of greater individual interest and value.

It is gratifying to know that this soil investigation was planned and is being conducted by a native of Maryland, who spent his boyhood in that section of the State which contributes the first material to the work, and was later a student of science in the University which is now so generously contributing to the success of his labors.

TOBACCO EXPERIMENTS:—In accordance with the intention stated in the last annual report, tobacco experiments have formed one of the leading features of the Station work, during the past season. This work has been divided into three branches:—1,—comparison of varieties of tobacco; 2,—the effects of different fertilizers on the same kinds of tobacco, tried on different soils; 3,—the results of varied and improved methods of curing.

Expert assistants were secured for different parts of the work, in this State, and from Virginia and North Carolina. The Station also received the cordial and efficient co-operation, throughout the season, of the Leaf Tobacco Association of Baltimore, and of several enterprising planters in different counties. There were some casualties and disappointments, but, as a whole, the experiments of the year were favorably conducted and concluded, except the final chemical parts. There is much of this laboratory work remaining and it is necessarily slow business. Upon its results and the commercial tests with the cured tobacco, rest the conclusions and deductions of the season. It is thought best to defer the detailed description and full report upon the work, until the chemical portion is completed. All can then be published as a bulletin. Therefore, only a brief statement of what has been done, will now be given.

Varieties:—Plants from pure seed of thirteen improved varieties, were grown under like conditions, here at the Station, and with reasonable success. Some loss was experienced from what is known as "frenching," which presents a subject requiring special investigation. The several varieties were also grown on plots of land differently manured or fertilized. The improved varieties mainly tried in other counties were the Orinoko and Saffrano. It is believed that both can be advantageously introduced and used, under certain favorable conditions. While detailed conclusions await the results of marketing the crop, it seems evident that the use of pure seed, carefully selected as to variety and adaptability, is by no means to be rejected. This is one of the ways in which the tobacco product of the State is to be improved. Although deterioration of introduced varieties may be found rapid, upon Maryland soil, this difficulty may be easily overcome by procuring the seed from a distance every year. If, as seems probable, the improvement in crop warrants so doing, an annual supply of new and pure seed is a small item.

Field Experiments:—The Leaf Tobacco Association of Baltimore recommended to us desirable locations in six counties, at which to conduct field trials, with liberal and progressive men to assist in the work. As a result, experimental acres were selected in five counties, carefully laid out, prepared and each divided into ten plots by the Station agents. Upon these plots different fertilizers were applied. Circumstances prevented the location of such an acre this year in St. Mary's, but it is hoped to include that county in the future. Samples of cured plants, from the several plots of these acres, are now passing through the laboratory. The points which it is hoped to develop are economy of production and effect upon quality and market value by the different methods of special feeding.

Curing:—The Association mentioned assisted the Station by a liberal cash contribution in bringing one of the patent Modern Tobacco Barns from North Carolina and setting it up for trial, for the present, in Calvert County. Mr. J. Benson Posey, upon whose place it is located, near Mt. Harmony, did his full share in connection with this trial. Flue-curing houses, with and without some of the peculiarities of the Snow process, were fitted up by the Station, or under its supervision, in Prince George's, Calvert and Charles counties. In all these, tobacco was cured by our expert helpers, of the standard Maryland type and of a few improved varieties. Samples of the same tobacco were cured, for comparison, by methods more common in the State. The chemical and commercial comparisons of all these, also remain to be made. The experience of the season shows that these improved methods of curing must be adapted to the conditions peculiar to this State. But having made these adaptations and acquired practical experience in managing the houses, it will be easy to demonstrate the economy of certain forms of improved curing; and it now appears that this will apply to the ordinary type of Maryland tobacco. A large part of the tobacco crop of this State is woefully neglected, and much actually ruined, every year, after being well and successfully grown. It is to improved methods in curing and marketing the crop that attention should be mainly given, for the relief of Maryland planters, and for raising the standard of Maryland tobacco.

Marls and Limestones:—Closely allied with our soil studies is the examination of the marls, limestones and other formations of agricultural interest, in various parts of the State. These will be ultimately brought into the geological and soil mapping and classification, but for the present most of the work done upon them is of a chemical nature. The numerous samples obtained and examined during the year are described in the appended report of the Station Chemist. In that connection some general information is introduced which may be found of practical value. It is interesting to note that year after year our efforts are rewarded by finding deposits of marl richer in plant food and agricultural value. The list published in this report contains the analyses of some marl samples from large deposits in Charles county, which compare favorably in content of potash and phosphoric acid, with the famous "green sands" of New Jersey, which have added so largely to the agricultural wealth of that State.

FEEDING EXPERIMENTS:—The Station now has pretty good facilities for experimental feeding, and it is proposed to do more or less of this annually. During the past year feeding experiments have been completed with swine, milch cows and beef cattle. The record of the pig feeding, which included the work of two years, and had reference particularly to the summer treatment of growing shotes, was issued as Bulletin No. 12, for March, 1891. The trial with milch cows had reference to changes in the composition of milk produced, as the effect of special feeding; the results were negative and unsatisfactory in character, and the trial should be repeated before the record is published. In the experiment with beef cattle, four very fine Hereford steers were the subjects, and the operations extended over ten weeks, involving much care and labor. The questions at issue were of a chemical and physiological nature, relating to the digestibility of corn silage and corn stover,—and the effects of acid in the food. The record is, therefore, embodied in the following report of the Station Chemist, and constitutes the greater portion thereof. The simpler matters of the relations of the food and feeding to gain in weight, or beef production, are reserved for use in a future bulletin, with other records of a similar character. The report upon the chemical aspects of this work deals with some of the fine points in the economy of feeding, or what may be called scientific feeding. The effort has been to make the record complete, and although this results in its being elaborate and somewhat intricate, with more figures and tables than are popularly approved, the work is so directly practical in its bearings that a careful perusal of the report is recommended to all interested in this line of farming operations.

Dairy Work:—The dairy interests of the State appear to be on the increase, especially in the form of creameries. Much dissatisfaction has been found to exist among the "patrons" of creameries, both proprietary and co-operative, over the now antiquated and manifestly unjust system of paying the same price per 100 lbs. for all milk, regardless of its quality. Although still practiced, as a rule, by the creameries in this State, this system has been generally rejected in the most progressive dairy regions in the country, and methods have been adopted for testing every lot of milk purchased or received at the creamery, and paying for it according to a fixed standard of quality. Interest, therefore, attaches to these new methods of milk-testing, or "fat tests," and the subject therefore, receives some attention in the Chemist's report.* A brief record is added, of a trial to determine the effect on the results of fat-testing, of delay in handling the milk samples taken for that purpose.

Agriculturist's Report:—The report of the Station Agriculturist, which will be found in later pages, contains the record of those portions of the work of the year, which have heretofore been presented under this head. Among these are Silos and Silage (or ensilage); Corn experiments; Variety tests with Oats and Wheat; the season's record on Grasses, Clovers and other Forage Plants; the Rotation Plots record and Potato experiments. These subjects will all be of more or less interest to different readers, who are referred to the report for all details and for such deductions or inferences as are justified by the record. The effects of different modes of cultivating fodder-corn, as well as of planting the same, are worthy of note; this year's record certainly justifies the advice to put the rows pretty close, seed thinly and cultivate very shallow, barely stirring the surface. In the potato work, although poor crops again prove the soil of this Station unsuited to this tuber, the same general conclusion is reached, in favor of planting whole potatoes of about egg-size. And again has been demonstrated the decided gain, here at any rate, of getting fresh Northern-grown stock for planting, every year.

*Later:—It is possible that it may be found necessary to omit this subject from this report and issue it later as a bulletin.

Horticulturist's Report:—The last report of the Station noted the fact that its horticultural work was being extended and given greater variety. The progress made in this direction will be seen from the report of the Station Horticulturist, for the past year, which is one of the appended papers. This deals with numerous subjects of interest to the gardener and fruit-grower, which need not be mentioned in detail, but special attention may be called to the section on Spraying with various solutions and mixtures, for preventing losses from plant diseases and injurious insects,—and the utensils for this work. The annual comparison of Strawberries, for 1891, including more varieties and more detailed work than the year before, was made the subject of the June Bulletin, No. 13; circumstances have delayed the distribution of this bulletin. An interesting series of experiments in Pruning, Root pruning and Planting of trees and vines, is nearly completed and will be made the subject of a future bulletin.

Station Improvements and Needs:—The building allowance for the current fiscal year has been mainly used in adding a wing to the stable, which provides sheds and storage room greatly needed, with tool-rooms, seed-room, work-shop, etc. This has been finished and painted. Desirable additions have been made to the scientific instruments, chemical apparatus and library.

During the coming year, the means available should be applied to fitting up the museum and some other interior improvements needed in the office building and the outbuildings. Yet it may be found expedient to defer these, and instead, to build one or more tobacco-curing houses.

As soon as it becomes possible, quarters should be built for one or two of the families of permanent employees, also a small green-house and a building specially adapted to the work of the horticultural department, including cellars or other storage for fruit and vegetables.

The annual allowence is so small, for such purposes, that these needs of the Station can be but slowly supplied.

Exhibitions and Meetings:—The policy has been continued of participating as often as possible in appropriate agricultural exhibitions and meetings held in different parts of the State. Several hundred dollars are expended in this way annually, and the Station officers give as much time to this branch of the work as can be spared from home duties. During the Autumn of 1891, exhibits were made by the Station in the counties of Baltimore, Frederick, Montgomery, Talbot and Washington; and by special authority of the Trustees, an additional exhibit was made at the Southern Inter-State Exposition at Raleigh, North Carolina. Representatives of this Station have attended and participated in public meetings held during the year in thirteen different counties in the State.

Visitors and Correspondence:—These two methods of intercourse with those who are interested in the work of the Station, are encouraged as much as possible, and both are increasing. No opportunity is lost to make it known that visitors, singly or in parties, with or without previous notice, are always welcome, and that effort will be made to make such visits pleasant and instructive. Those who cannot come are encouraged to write, suggesting and inquiring, and the Station officers give such letters every possible attention. This correspondence now constitutes a large part of the office work, and embraces a great variety of subjects connected with agriculture and horticulture.

Publications:—The following are the publications of the Station for the past year:

The Third Annual Report, dated January, 1891, pages 75 to 146.

Bulletin No. 12, March,—Pig Feeding; pp. 147 to 160.

Bulletin No. 13, June,—Strawberries; pp. 161 to 200.

Bulletin No. 14, September,—Wheat; pp. 201 to 216.

Bulletin No. 15, December,—Insects Injurious to Wheat; pp. 217-232.

Special Bulletin "D.," February,—Analyses of Commercial Fertilizers.

Special Bulletin "E.," August,—Ditto.

These bulletins and reports have been mainly distributed by mail, although all of them have not yet been sent out.

Attention is called to the comments in the last Station Report upon the nature, publication and distribution of the documents prepared here, and the advantages which would result to have all this printing done by the State Printer.

THE STATION STAFF:—The only change in the scientific staff of the Station during the year, has been the addition of Prof. Milton Whitney as Physicist. He has been for some years connected with the Experiment Stations of North Carolina and South Carolina, being vice-director of the latter. The best evidence of the industry and efficiency of all the members of the Station staff is in the several division reports, which will be found in the following pages.

The acknowledgments of all the workers at our Station are due to the Board of Trustees, and especially to its Agricultural Committee, for continued confidence and support, and to the public, for patient interest and friendly encouragement.

HENRY E. ALVORD, *Director.*

MARYLAND AGRICULTURAL EXPERIMENT STATION.

THE ANNUAL FINANCIAL REPORT, 1890-91.

The Maryland Agricultural Experiment Station in account with the United States Appropriation.

1891.				DR.
June 30.	To Receipts from the Treasurer of the United States in four payments, per appropriation for the year ending June 30, 1891, under Act of Congress, approved March 2, 1887,—see Ledger page 306		$15,000 00	
				$15,000 00

1891.	CREDITS.	LEDGER PAGE.	AMT.	
June 30.	By Salaries	206	$6,795 00	
"	Labor	220	2,551 23	
"	Supplies	232	1,692 08	
"	Freight and Expressage	242	209 25	
"	Postage and Stationery	246	134 93	
"	Printing and Office Expenses	250	951 65	
"	Library	256	266 80	
"	Tools and Apparatus	258	369 75	
"	Fencing and Drainage	284	168 00	
"	Incidental Expenses	293	79 64	
"	Exhibition and Meetings	311	239 68	
"	Feeding Experiments	317	190 98	
"	Travel and Board Meetings	321	317 37	
"	Soil Examinations	331	229 48	
"	Scientific Instruments	264	56 00	
"	Building and Repairs	279	748 34	
				$15,000 00

I hereby certify that the foregoing statement is a true copy from the books of account of the said Experiment Station.

(Signed:) JOS. R. OWENS, *Treasurer.*

NOTE:—Certificate of Auditors appended to original, forwarded to the Secretary of the Treasury, Washington, D. C.

REPORT OF THE PHYSICIST.

By Prof. Milton Whitney.

SOIL INVESTIGATIONS.

Introduction.

It is proposed at this time to give a brief account of the soil investigations carried on by the Station and attempt to point out the application of the results and conclusions to the explanation and solution of problems in practical agriculture.

We are glad to report that the U. S. Government has taken up this work, and, through the Weather Bureau of the Department of Agriculture, has placed a sum of money at our disposal to enable us to complete some work on hand in order to prepare a full report or monograph, to be ready for publication by next July. In view of the fact that the report to be issued by the Government will of necessity be much fuller and more exhaustive than this can be, and will contain a detailed description of the methods, formulae and data upon which our lines of reasoning are based, we will introduce into this report only such statistical and other data as will make the narrative complete—referring all who wish to follow the subject more closely and in further detail to the Government report.

It has taken six years of constant application, observation and study, in the field, plant house and laboratory, to gain a clear idea of the nature and structure of the soil in its relation to meteorology and agriculture. When, in the fall of 1890, the work was commenced here in its application to the soils of Maryland, several fundamental principles of soil physics still remained to be worked out. This required the use of very expensive apparatus, only to be found in a well-equipped physical laboratory. It was essential, also, that the work be based upon the most thorough geological data to show the area and distribution of the different soil formations. There was no reliable geological map of the State, and the Director of the U. S. Geological Survey stated that the Professors of Geology of the Johns Hopkins University had all the available data, and were themselves working out in more detail the geology of Maryland, and advised a co-operation with them in this soil work.

The work of this division of the Experiment Station on the investigation of soils was, therefore, located at the Johns Hopkins University. By permission of the Trustees of the University the work was moved in June to their large estate of Clifton, on the Harford Road, where it is at present being carried on. The reasons for this and our relations with the University are more fully set forth in the Director's report.

The President of the University and the Professors in the Departments of Chemistry, Geology and Physics have shown, from the first, an interest in the work and a cordial spirit of co-operation, with a desire to have us make a practical application of their work and information.

ARGUMENT.

It takes really very little experience for one to judge at a glance whether a soil is suited to grass or wheat or tobacco or watermelons, and he has but to turn up a small handfull of earth to see if the soil is in good condition, as regards moisture, for the growing crops. And yet, agricultural chemists have worked over this problem for years, arguing points from minute differences in chemical composition of the soils or plants, which their most refined methods make none too sure, overlooking the fact that the farmer can tell from the *appearance* whether a soil is in "good heart" and what it is best fitted to grow. The farmer cannot see these minute differences in chemical composition. He judges from the general appearance of the land, the physical structure of the soil.

Those of us who are engaged in agricultural investigations, even in soil studies, are not as far advanced as the farmer in our knowledge of the soil, nor will we be until we can understand and explain these visible signs upon which he bases his judgment. He has kept up with our work on the chemical composition of soils and has applied it and made it his own. But he goes further than we have gone, for he can tell, as no chemical means will enable us to judge, whether the land is in good condition, is fertile, has body and will hold manures, is strong or will shortly run out, is dry and leachy or retentive of moisture. He can tell what class of plants it will best produce. In this lies the key to all soil investigations. Chemical analysis has its part to play, but we have yet to get the key to the interpretation of its results. And this key is to be found in the study of the physical structure of the soil and the physical relation to meteorology and to plant growth. Meteorology has not done, and is not doing, its best good for agriculture. While we admit it is very important to have the rainfall data furnished by the Weather Bureau, still, as the rain does not benefit the crops until it enters the soil, it is very essential that the rainfall be studied below, as well as above, the surface of the ground.

Crop production is not directly limited by the amount of rainfall, but by the moisture in the soil. Six inches of rainfall a month may mean a good season, or, with this same amount differently distributed throughout the month, the crops may be injured by excessive wet or by prolonged drought. Changing seasons of wet or dry, hot or cold, have far more effect on the crops than any combination of manures.

There is a certain type of land in this State, in a certain geological formation, which is left out in pine barrens as it is too poor to put under cultivation; another type, in a different geological formatian, is well suited to melons and garden truck; still other types, to tobacco, wheat and grass. This is not a matter of mere plant food. No addition of any amount or any combination of available plant food will at once enable a good wheat crop to be produced on the soil of the pine barrens, or on the light truck lands. It is a matter of available water rather than of available plant food, and if after some years the light land is brought up to produce good yields of wheat, the whole appearance and structure of the soil will be found to have changed, and with it, the relation of the soil to the movement of water—*to the movement of the rainfall after it enters the soil.*

And so in the deterioration of land, in the deterioration of our tobacco and wheat lands. It is not due to loss of plant food so much as to the causes which change the whole appearance of the soil to the eye—a change of the physical structure of the soil, a change in the relation of the soil to the movement or circulation of water.

Our work, then, is on the physical structure of the soil and its relation to the circulation of water—the movement of the rainfall after it enters the soil, and the physical effect of fertilizers and manures thereon, as related to crop production.

Summary of the Results.

This report will treat first of the underlying principles governing the circulation of water in the soil, then of the different soil types found in the State, of their structure and relation to the circulation of water, leading up to the application of these principles in a discussion of the improvement of lands. A summary will be given here, outlining the body of the report, so that it may be followed more easily.

I. The circulation of water in the soil.

a. Due to gravity or the weight of water acting with a constant force to pull the water downward, *and also*, to surface tension or the contracting power of the free surface of water, (water-air surface,) which tends to move the water either up or down or in any direction, according to circumstances.

b. The ordinary manures and fertilizing materials change the surface tension or pulling power of water.

II. The effect of fertilizers on the texture of the soil.

a. There is a large amount of space between the grains in all soils in which water may be held. The rate of movement of the water will depend: 1. Upon how much space there is. 2. Upon how this is divided up, *i. e.* upon how many grains there are per unit volume of soil. 3. Upon the arrangement of the grains of sand and clay.

b. Flocculation—a phenomenon of great importance in agriculture—changing the arrangement of the grains and consequently the texture of the soil.

III. The volume of empty space in soils.

IV. The relation of geology to agriculture.

V. Soil types.

a. Reasons for establishing soil types.

b. The very evident difference in texture is the probable cause of the difference in relation to plant growth and to local distribution of crops.

c. Soil types in Maryland and the samples from which they are made.

VI. Mechanical analysis of the type soils.

VII. Approximate number of grains per gram of soil.

VIII. Approximate extent of surface area per cubic foot of soil.

IX. The circulation of water in these type soils.

a. The relative rate of circulation of water in soils short of saturation is very different in these type soils and probably explains the difference in relation to crop production.

b. The relative rate of circulation of water in these soils when fully saturated.

c. The influence of the total volume of space.

d. The rate of circulation of water is relatively faster in light sandy lands, when far short of saturation, than in heavier clay lands, but it may be far slower in these same light lands when fully saturated, owing to the less amount of space in the soil.

X. The improvement of soils.

a. In soils having as much clay as the type requires, the grains of clay may be rearranged by causing flocculation, or the reverse, by the use of ordinary fertilizing materials.

b. In soils having less clay than the type: 1. The grains may still be rearranged, or, 2. organic matter may be precipitated from solution within the soil, in light, flocculent masses, with lime, acid phosphate, or the proper mineral manures, or constituent of the soil itself, and so fill up the spaces and retard the rate of circulation of the water.

I. The Circulation of Water in the Soil.

The motive power, which causes water to move from place to place within the soil, consists of two forces: gravity, or the weight of the water itself, and surface tension. Gravity tends to pull the water downward, and acts with a constant force per unit mass of water. Surface tension, or the contracting power of any exposed water-surface, may move the water in any direction within the soil, according to circumstances. It may act, therefore, *with* gravity to pull the water down, or *against* gravity to pull it up. This has an important practical bearing on the movement of water in sandy lands, as we shall show in speaking of the application of these principles to our type soils.

The force of gravity need not be further considered here.

Surface tension is the tendency which any exposed surface has to contract to the smallest possible area, consistent with the weight of the substance. If a mass of water is divided, or cleft in two, leaving two surfaces exposed to the air, the particles of water on either surface, which were before in the interior of the mass and attracted from all sides by like particles of water, have now water particles on only one side to attract them, with only a few air particles, comparatively very far apart, on the other side, where formerly was a compact mass of water. All the surface particles of water will therefore be pulled from within the mass of water, and the surface will tend to contract as much as possible, leaving exposed the smallest number of surface particles, and causing a continual strain or *surface tension*. On any exposed water-surface, there is always this strain or tension, ready to contract the surface, when it may.

It is a constant, definite force per foot of surface, for any substance at a given temperature. In the case of liquids and solutions, in which we are most interested, it varies with the nature of the liquid and the substance in solution.

This is *surface tension;* and we have it in the soil as a strain or tension along the free surface of water within the soil, which tends to contract the surface and so move the water from one place to another as it is needed.

There is, on the average, about 50 per cent. by volume of space within the soil which contains no solid matter, but only air and water. This we shall call *empty space*. In a cubic foot of soil there is about half a cubic foot of empty space, but this is so divided up by the very large number of soil grains that the spaces between the grains are extremely small.

When a soil is only slightly moist the water clings to the soil grains in a thin film. It is like a soap bubble with a grain of sand or clay inside, instead of being filled with air. Where the grains come together the films are united into a continuous film of water throughout the soil, having one surface against the soil grains and the other exposed to the air in the soil. As the soil grains are surrounded by this elastic film, the tension on the exposed surface of the water will support a considerable weight, for the soil grains, thus enveloped, are extremely small and have many points of contact around which the film is thicker and is held with greater force.

If more water enters the soil the film thickens, and there is less exposed water-surface. If the empty space is completely filled with water there will be none of this exposed water-surface, and therefore, no surface tension. Gravity alone will act and with its greatest force. If the soil is nearly dry, there will be a great deal of this exposed water-surface, a great amount of surface tension, and with so little water present, gravity will have its least effect.

The grains in a cubic foot of soil have, on the average, no less than 50,000 square feet of surface area. There is less, of course, in a light sandy soil, and more than this in a clay soil. If there is only a very small amount of water in the soil the film of water around the grains will be very thin, and there will be nearly as much exposed water-surface as the surface area of the grains themselves. If a cubic foot of soil, thus slightly moistened, and having this large extent of exposed water-surface, be brought in contact with a body of soil fully saturated with water, in which there is none of this water-surface, the water-surface in the drier soil will contract, the film of water around the grains will thicken and water will be drawn from the wet into the dry soil, whether it be to move it up or down, until, neglecting gravity or the weight of water itself, there is the same amount of water in the one cubic foot of soil as in the other. When equilibrium is established there will be the same extent of exposed water-surface in these two bodies of soils.

When water is removed from a soil by evaporation or by plants, the area of this exposed water-surface is increased, and the tension tends to contract the surface and pull more water to the spot.

When rain falls on rather a dry soil, the area of the exposed water-surface in the soil is diminished, and the greater extent of water-surface below contracts and acts, with gravity, to pull the water down.

By numerous careful and verified experiments, we have found that fertilizers change this surface tension and modify the contracting power of the free surface of water to a remarkable degree, and so modify thepower which moves water from place to place in the soil.

The following table gives the surface tension of a solution in water of several of the ordinary fertilizing materials. This list is not complete, and the solutions used were of any convenient strength. The results are preliminary to give material for more thorough and detailed investigation. The surface tension is expressed in gram-meters per square meter, that is, on a square meter (or yard) of liquid surface there is sufficient energy to raise so many grams to the height of one meter (yard.)

TABLE 1:—THE SURFACE TENSION OF VARIOUS SOLUTIONS.

(*Gram-meters per square meter.*)

SOLUTION OF	SP. GR.	*	MEAN.	HIGHEST.	LOWEST.
Salt..............	1.070	6	7.975	8.126	7.796
Kainit.............	1.053	6	7.900	7.993	7.805
Lime...............	1.002	4	7.696	7.750	7.674
Water..............	1.000	18	7.668	7.923	7.506
Acid Phos..........	1.005	4	7.656	7.800	7.563
Plaster............	1.000	9	7.638	7.730	7.572
Soil extract.......	1.000	5	7.089	7.166	6.969
Ammonia............	0.960	6	6.869	6.950	6.826
Urine..............	1.026	10	6.615	6.740	6.471

* Number of measurements from which the mean is taken.

WULLNER GIVES THE FOLLOWING:*

	SP. GR.	TENSION.
Water..............	1.000	7.666
Sulphuric acid........	1.849	6.333
" "	1.522	7.610
" "	1.127	7.556
Hydrochloric acid..	1.153	7.149
Nitric acid......	1.500	4.275
" "	1.270	6.768
" "	1.117	7.098
Salt.......... ..	1.200	8.400
Nitrate of potash.....	1.137	7.276

*Lehrbuch der Experimental Physik, Vol. I., p. 341.

The soil extract was made by shaking up a little soil with just sufficient water to cover it; the water was afterwards filtered off and used for the determination. It will be seen from the table that this contact with the soil reduced the surface tension of water very considerably. There is little doubt that the surface tension of soil moisture is very low, much lower than that of pure water. Salt and kainit, on the other hand, increase the surface tension of water very considerably and raise it far above that of the soil extract. This probably explains the fact, which has been often commented on, that an application of salt or kainit tends to keep the soil more moist. This has often been remarked in connection with the application to a clover sod. By increasing the surface tension of the soil moisture they increase the power the soil has of drawing water up from below in a dry season.

Ammonia and urine lowered the surface tension of water considerably below that of the soil extract, and far below that of pure water. This, probably, also explains a matter of common observation, that the injudicious use of excessive quantities of organic matter is liable to "burn out" a soil in a dry season, because by reducing the surface tension, water can less readily be drawn up from below.

This opens up a field of investigation on the determination of the surface tension of the moisture in various soils, and a more extensive and more systematic study of the effect of various fertilizing materials on the surface tension of water and soil extract, and it opens up a wide field in its application to practical agriculture and the use of manures and fertilizers.

This effect of fertilizing materials in changing the surface tension of a liquid, and thereby changing the force or power which moves water from place to place in the soil, is only a first effect, as the continued use of these fertilizing materials may change the texture of the soil itself and the relation of the soil to the circulation of water.

II. The Effect of Fertilizers on the Texture of the Soil.

Surface tension may be expressed in another way. The *potential* of a single water particle is the force which would be required to pull it away from the surrounding water particles and remove it beyond their sphere of attraction. For simplicity, it may be described as the total force of attraction between a single particle and all other particles which surround it. With this definition it will be seen that the potential of a particle on an exposed surface of water is only one-half of the potential in the interior of the mass, as half of the particles which formerly surrounded and attracted it were removed when the other exposed surface of water was separated from it. A particle on an exposed surface of water, being under a low potential, will therefore tend to move in towards the center of the mass where the potential, i. e., the total attraction, is greater, and the surface will tend to contract so as to leave the fewest possible number of particles on the surface.

If instead of air there is a solid substance in contact with the water the potential will be greater than on an exposed surface of the liquid, for the much greater number of solid particles will have a greater attraction for the water particle than the air particles had. They may have so great an attraction that the liquid particle on this surface, separating the solid and liquid, may be under greater potential than prevails in the interior of the liquid mass. Then the surface will tend to expand as much as possible for the particles in the interior of the mass of liquid will try to get out onto the surface. This is the reverse of surface tension. It is surface pressure, which may exist on a surface separating a solid and liquid.

If two small grains of clay, suspended in water, come close together, they may be attracted to each other or not, according to the potential of the water particles on the surface of the clay. If the potential of the surface particle of water is less than of a particle in the interior of the mass of liquid, there will be surface tension and the two grains will not come together because this would enlarge the surface area and increase the number of surface particles in the liquid. If, on the other hand, the potential of the particle on the surface of the liquid is greater than the potential of a particle in the interior of the liquid mass, the surface will tend to enlarge and the grains of clay may come close together and be held there with some force, as their close contact increases the number of surface particles in the liquid around them. This probably explains the phenomenon of flocculation, a phenomenon of great importance in agriculture.

Muddy water may remain turbid for an indefinite time. If a trace of lime or salt be added to the water the grains of clay *flocculate*, that is, they come together in loose, light flocks, like curdled milk, and settle quickly to the bottom, leaving the liquid above them clear. Ammonia and some other substances tend to prevent this and to keep the grains apart, or to push them apart if flocculation has already taken place. This is similar to the precipitation of some solid matters from solution. When lime is added to a filtered solution of an extract of stable manure, the organic matter is precipitated in similar loose, bulky masses.

It will be remembered that there is, on an average, about 50 per cent. by volume of empty space in the soil. This empty space is divided up by a vast number of grains of sand and clay. If these grains are evenly distributed throughout the soil, so that the separate spaces between the grains are of nearly uniform size, water will move more slowly through the soil than if the grains of clay, through flocculation, adhered closely together and to the larger grains of sand, making some of the spaces larger and others exceedingly small.

We have, then, this principle to work on in the improvement of soils. In a close, tight clay, through which water moves slowly, the continued use of lime may cause flocculation, the grains of clay may move closer together, leaving larger spaces for the water to move through. On the other hand, there are soils in which the clay is held so closely to the grains of sand as to give the soil all the appearance and properties of a sandy soil, although there is as much clay present as in many a distinctively "clay soil."

Again, in a light sandy land, lime may precipitate the organic matter from solution within the soil, in light, bulky masses, which will fill up the spaces and retard the rate of circulation of water.

And so, if judiciously used, lime may be the "best fertilizer" for a light sandy soil or for a heavy clay land. In the one case, there must be sufficient organic matter for the lime to act on or it will injure the soil; in the other case, there is no such need of organic matter in liming a tight clay soil, and too much of it may be decidedly injurious.

We will speak of this more at length when we come to speak of the application of these principles to the improvement of soils.

III. The Volume of Empty Space in Soils.

There is, on the average, about 50 per cent. by volume of empty space in the soil. The amount in the soil proper will vary with the stage and state of cultivation, but the empty space in the undisturbed subsoil will remain fairly constant. The amount of space has not been determined in the soils of Maryland, for the determination requires that an exact volume of soil be removed from the field, and this takes much time and careful work. This will be made the subject of some future investigation, and for the present our work must be based upon determinations which have been made elsewhere.

The amount of space has been determined in a number of subsoils in South Carolina, in their natural position in the field, taking in a wide range of soil formations. The per cent. by volume of empty space is given in the table following.

TABLE 2:—EMPTY SPACE IN SO. CA. SUBSOILS.

Per Cent. by Volume.

78.	Wedgefield, (sandy land)	41.80
66.	Gourdins	42.82
57.	Sumter	44.10
80.	Lesesne	46.41
57a.	Sumter	47.70
69.	Gourdins, (Mr. Roper)	49.74
64.	Lanes	50.00
74.	Wedgefield, ("Red Hill" formation)	50.03
69a.	Gourdins	50.25
53.	Charlotte, N. C.	52.05
71.	Gourdins, ("Bluff land")	55.40
53a.	Charlotte, N. C.	57.19
76.	Wedgefield, ("gummy land")	58.46
76a.	Wedgefield, ("gummy land")	61.54
42.	Chester, ("pipe clay")	65.12

The first six subsoils, which may be considered essentially sandy, have, on the average, 45.43 per cent. by volume of empty space. The remaining nine subsoils, which are from essentially clay lands, have, on the average, 55.55 per cent, by volume of empty space.

In "How Crops Feed," Johnson gives the weight of a cubic foot of sandy soil as 110 pounds, and of a cubic foot of a clay soil as 75 pounds. This would give about 34 and 55 per cent. by volume of empty space, respectively, in these soils.

It is unfortunate that the term "light soil" has become commonly applied to that which actually weighs a good deal more than an equal bulk of what is called "heavy soil."

In our own work, unless the actual determinations have been made, we have assumed that the subsoil of "light sandy land" has 45 per cent. by volume of empty space, and that of a strong clay land, 55 per cent. If all the space within these soils was filled with water, they would contain 22.41 and 31.55 per cent. *by weight* of water, respectively.

For the empty space in our soil types, to be presently described, we have assigned, as probable, values based on this South Carolina work.

IV. The Relation of Geology to Agriculture.

We shall use in this report certain geological names which may be unfamiliar to many of our readers, and it seems well to insert a section explaining the reason for this and the general relation of geology to agriculture.

We shall show presently that there are well-marked types of soil in this State; some suited to grass and wheat, others to wheat but rather light for grass, others to tobacco, truck, or left out as barren wastes. The texture and general appearance of these soils differ very much so that one can tell at a glance to what kind of crop each of these types is best adapted. We shall show further, that from this difference in texture, which is so very apparent to the eye, there is a marked difference in the relative rate with which water moves within the soil, and the ease with which the proper amount of water may be maintained and supplied to the crop.

As crops differ in the amount of water which they require, and in the amount of moisture in the soil in which they can best develop, this difference in the relation of these soil types to water probably accounts for the local distribution of plants.

In green-house culture the same kind of soil is used for all kinds of plants, but great judgment is required in watering the plants. Some plants require a very wet soil, others must be kept quite dry. The amount of water required will not be the same at different stages of development of the plant. During the earlier growing period the soil is kept quite wet, but during the fruiting or flowering period the soil is kept much drier. Each class of plants requires in this way special treatment, and it is through this judicious control of the water supply in the soil and the temperature of the air, that the best development of each class of plants is attained.

Our soil types, therefore, in having different relations to the circulation of water, partake somewhat of these artificial conditions in green-house culture, and on each of them certain classes of plants will find conditions of moisture best suited to their growth and development.

Our soils have been formed from the disintegration, or decay, of rocks. The crystalline rocks, such as granite, gabbro and serpentine, from which the soils of Northern Central Maryland are derived, have been formed by the slow cooling of the earth's crust. They are made up of different minerals, the most common of which are quartz, feldspar and mica, cemented together usually with lime or silica. The kind of rock is determined by the kind and relative amount of each of these minerals of which it is made. When the rocks decay, the cementing material is dissolved and carried off, and many of the minerals themselves are changed. Now, the texture or the relative amount of sand and clay contained in the soil resulting from the disintegration of these rocks, will depend upon the kind of rock, that is, upon the minerals of which it was composed.

The material resulting from the disintegration of these rocks is slowly washed away and carried off by streams and rivers. As the current of water becomes slower near the sea, the sand is deposited along a rather narrow shore line, while the finer particles of clay are carried further and deposited over wider areas. The conditions where some parts of this material are being deposited may be favorable to the growth of coral and of various kinds of shell-fish, so that their remains accumulate in beds of great thickness, giving the material for the limestone of the present day. These sediments are thus assorted out by subsidence in water of different velocities, as though they had been sifted and the different grades of material spread out over wide areas.

The sediments, being slowly deposited in beds of great thickness, are converted into rocks through the agency of heat and great pressure to which they are subjected by the accumulation above, and so sandstones, limestones and shales have been formed; the sandstone, where the coarser material has been deposited near the shore; the limestone, where the shells have accumulated; and the shale, where the fine mud has been spread out over a wider area of still water.

It is from the disintegration of these "sedimentary" rocks, as they are called, which have since been raised above the surface of the water, that the soils of Western Maryland have been formed. There are the limestone valleys, where shell-fish were once abundant, and where now is a strong clay soil, well adapted to grass and wheat; the sandstone ridges, some of which, resisting decay, form the mountain ranges, while others, made of finer grains of sand and less firmly cemented together, form some of the fertile hill and valley lands; the shales, in which the grains of mud were so extremely small that they adhere so closely to each other that they do not thoroughly disintegrate, and the soil is filled with fragments of the rock and supports but a scanty mountain pasture.

The soils of Southern Maryland and the Eastern Shore are of more recent origin. The sediments have not, as yet, been subjected to the great heat and pressure required in rock-making, and they are still in the first stages of formation.

Now, geology defines the limits and areas of these different formations and of these different rocks, and, as I have shown, that these rocks determine the texture of the soil, a thorough and detailed geological map of the State should answer for a soil map. Any one familiar with the texture of the soil, or kind of soil, formed by the disintegration of granite, gabbro, and the different kinds of limestones, sandstones and shales, should be able to tell by a glance at the map the position and area of each kind of soil. Each color on the map would represent a soil formation of a certain texture, in which the conditions of moisture, under our prevailing climatic conditions, would be best adapted to a certain crop.

Such a geological or soil map would be of the greatest aid to any one interested in the agricultural lands of the State. It seems to me that such a map of the soil formations in this State would be of great benefit to agriculture in the hands of farmers and of those interested in immigration and in the material advancement of the agricultural interests of the State. Not only so, but I think the interest of this work demands the most thorough and detailed geological survey so that each of these soil formations may be carefully located and outlined. The wheat, tobacco, truck and barren lands of Southern

Maryland are each confined to certain different geological formations for their best development, and a geological map of this portion of the State should show the area and distribution of the lands best adapted to these crops.

There is usually some marked and distinctive botanical character in the herbage of these different soil formations. We have pine barrens, white oak lands, black jack lands, chinquapin lands, grass lands, wheat lands and truck lands. These names convey a very good impression of the character and texture of the soil, and they should be more generally used. When a soil formation is spoken of as black jack land, the name conveys a distinct impression of the kind of soil, for a soil must have a certain characteristic texture to produce such a growth.

We have not been able to include this botanical work on the different soil formations of the State this year, but it will be made a subject of careful investigation. In the mean time and until a description better suited to the agricultural interests can be given, the geological names will have to be used to designate these different soil formations.

V. Soil Types.

The soils of the State appear, at first sight, to offer an endless field of research in the great variety often seen on a single farm and in the same field, but a more comprehensive view of the matter will show this to be due to local causes, which have mixed up and modified the original soil formation. These local modifications may be neglected for the present, until the general features of the representative soils of the region have been worked out.

The characteristic properties of great soil formations, or soil types, must first be determined, and then more detailed work may be done in the examination of soils of local interest. Why will not truck, tobacco, wheat and grass grow equally well on all soils? It is not so much a matter of plant food as of the texture of the soil. No addition of mere plant food in the form of fertilizers or manure will change at once a light sandy soil into a good wheat land. It takes no very great experience to tell at a glance the condition of a soil, and to what class of plants it is best adapted. It is from the *appearance* of the soil, that is, from the texture and structure, that this judgment is formed.

This is the key to soil investigations. It is not until this problem has been mastered and these very evident differences in soils have been explained, that the real and full value and application of the chemical determinations in plants and soils will be seen. As a rule, the chemical analysis of a soil will not enable a farmer to determine to what his land is best adapted; but, on the contrary, the farmer, from his experience and judgment, must inform the chemist on this point, and must tell him of the strength and condition of the land.

What are the characteristic properties of a good wheat land, of the best tobacco soil, of the best grass land, of the best land for market truck? What is it in the appearance of a soil which enables a farmer to place it in one or the other of these classes? The truck lands of Southern Maryland are "lighter" in texture than the best tobacco lands, and still "lighter" than the best wheat lands. The wheat lands of Southern Maryland are "lighter" than the grass and wheat lands of Northern and Western Maryland.

It is only after the characteristic properties of a number of soils of well marked agricultural value have been carefully determined that we may hope, by examination and comparison, to suggest methods for the improvement of other soils of local interest. We must have, first of all, a basis of comparison in well known and representative soils.

We have made several extended trips into Southern and Western Maryland, collecting a large number of samples of soils and sub-soils of representative agricultural value and importance. These samples have been arranged in groups, according to their agricultural value and their geological origin; and equal weights of the samples in each group have been mixed together, forming a composite sample representing the *type* of the soil formation. We have, in this way, classified the soils of all the principal agricultural regions of the State, and they are represented by comparatively very few type samples, as shown in the following table:

The formations are not given in the order of their geological origin but according to their agricultural importance and distribution.

Table 3:—Soil Types in Maryland.

Sample.	Soils adapted to,	Localities.	Geological formation.
276.	Pine barrens.	* (2)	Lafayette.
283-4.	Market truck.	(6-8)	Eocene.
285-6.	Tobacco.	(9-9)	Neocene.
279-80.	Wheat.	(7-14)	Neocene.
277-8.	Wheat soil of river terraces.	(5-5)	Columbian terrace.
....	Barren clay hills.	....	Potomac.
.....	Grass and wheat.	.....	Trenton chazy limestone.
287-8.	Grass and wheat.	(2-4)	Helderberg limestone.
238.	Grass and wheat.	(1)	Catskill.
281-2.	Grass and wheat.	(4-5)	Triassic red sandstone.
290.	Mountain pasture.	(3)	Oriskany.
289.	Poor mountain pasture.	(6)	Chemung, Hamilton, Niagara, Clinton.

The Lafayette, Eocene, Neocene and Columbian terrace formations occur in Southern Maryland; the Potomac formation is a narrow belt extending across the State on the line of the B. and O. and the B. and P. railroads; the Trenton chazy limestone forms the Frederick and Hagerstown Valleys; the Triassic red sandstone covers a considerable area to the north and south of the Frederick Valley; the Helderberg limestone, Catskill, Oriskany, Chemung, Hamilton, Niagara and Clinton formations form the valleys, hills and mountains of Western Maryland.

In the Piedmont Plateau of Northern Central Maryland, there are grass and wheat soils from gneiss, granite, gabbro and limestone; wheat and tobacco soils from mica schist; corn lands from sandstone; and barren hills from serpentine.

There has been no opportunity this year to collect samples of soils from the Eastern Shore.

There are two or three mountain formations which occur in such small areas that their soils have not been considered here. The coal formation is so uneven, with its succession of sandstones, limestones and shales, which have not been separated on the geological map, that, although it is of importance from covering a large area, it has not, as yet, been considered.

The coarse sands of the quarternary formation, covering the extreme lower part of the State, have not been sampled.

In the table, where a double number is given, the first number refers to the sample of soil, and the second number to the subsoil. Where a single number is given for a type, there is no perceptible difference between the soil and subsoil in the localities visited.

The figures in brackets under * give the number of localities from which samples were taken to make up the samples of type soils and subsoils.

The grass and wheat soils of the different types in the Piedmont Plateau and Western Maryland differ in texture and in relative fertility, and should be distinguished by different botanical characters, but for the present the geological names will be used to designate them.

The truck, limestone and Catskill lands are important soils, which should have more localities represented in the type samples.

To establish a type, samples should be taken from as many localities as possible; from ten localities at least, even in as small a State as Maryland. The type sample is, therefore, a sort of composite sample made by mixing equal weights of samples from a number of localities in each formation.

A description of the samples themselves will be given later. They were taken with a spade, or auger, the *soil* being taken down to the change of color, and the *subsoil* below this to a depth depending upon the nature and depth of the material, usually 12 to 18 inches.

The soil of the pine barrens is a coarse yellow sand, very loose and incoherent when worked, but packed exceedingly hard and tight in the subsoil. The lands are very infertile. These soils should be more carefully examined, and more samples of them should be taken for our type sample, as they cover such an extensive area in Southern Maryland with pine barrens, which will some day, when agricultural lands rise in value, have to be taken up and improved.

Most of the truck supplied to the Baltimore and the larger Northern markets, from this State, is produced on a rather narrow belt bordering the Bay and rivers from Baltimore south to West River. This area is largely in the eocene formation, although far down on the river necks the lands are coarser and belong to a more recent formation.

The truck lands proper are a fine textured, grey or reddish grey, sand. They are naturally fertile, but require care to keep up their fertility. The texture of the soil admits of vast quantities of manure and organic refuse being used for forcing the vegetables, without fear of clogging the soil. The texture of these lands adapt them well to the requirements of market gardening.

The soils are derived from the weathered green sands, similar in composition to the green sand marls of New Jersey, so that in chemical composition they should be rich in potash and phosphoric acid.

The soils are too light in texture for wheat, although, in the high state of cultivation to which they are brought for market truck, good crops of wheat may be produced, but at such a cost, and under such artificial conditions, that the soil cannot, in any sense, be called a wheat soil.

Samples have been taken from too few localities in the truck area to make the type samples of soil and subsoil (Nos. 283-4) perfectly satisfactory. They are probably heavier than the best type of truck land. The collection of these samples has been rather incidental to other work, as most of our attention has been given this year to the tobacco and wheat soils of Southern Maryland. The great truck area between Baltimore and Annapolis is not represented in these samples.

The best tobacco and wheat lands in Southern Maryland, apart from the river terraces, seem to be confined to the diatomaceous earth horizon of the neocene formation, or of a later formation made over out of this same material. The formation extends obliquely across the peninsula, in rather a broad belt from South River and Herring Bay to Pope's Creek on the Potomac River.

The subsoil of the wheat land is a strong clay-loam of a very marked and characteristic texture and yellow color. It is usually not more than 4 to 6 feet deep, resting directly on the white diatomaceous earth, and appears to be formed from this by weathering, as there is no distinct line of separation. The samples of both wheat and tobacco subsoils still contain many diatoms. The weathering of this diatomaceous earth probably takes place quite rapidly on exposure, and some interesting changes occur, including a local accumulation of clay in the yellow subsoil, which should be further studied. We have the material for this work, but it has not been worked out yet.

Wheat and tobacco are commonly grown on the same land in alternate years or in longer rotation, but the strongest and best wheat land is too heavy for tobacco. It gives a large yield but makes a coarse, thick tobacco leaf which is sappy and cures green and does not take on color. The best class of tobacco lands, where the finest grade of tobacco is produced, is of lighter texture and too light for the best wheat production. The best tobacco soils around Upper Marlboro appear to be at a lower elevation than the strongest wheat lands, and are rather heavier in texture than the better grade of tobacco lands in the Nottingham, Aquasco and Chaneyville regions. These latter are more loamy, although they are still over very pure deposits of diatomaceous earth.

At a road cut near Upper Marlboro there is an exposure of diatomaceous earth, probably 30 or 50 feet deep. The upper part of this exposure is very pure white earth, very light and porous. A strong wheat subsoil rests directly on this. The lower part of the exposure is decidedly more sandy in texture, and more like the typical tobacco land. The lighter texture of the tobacco soils may be due to local modifications of original wheat lands, or they may themselves turn into good wheat soils by further weathering, or these tobacco lands may belong to a different horizon of the diatomaceous earth formation. The last seems very probable, but it may be due to different causes in different localities.

Lime is the great fertilizer for all classes of soils in this region. On the lighter soils lime must be used only with organic matter, or it will "burn out the land." Lime every five years, and clover, will keep up their wheat lands. But this rule is being neglected. Lime is applied more rarely and the lands are becoming clover-sick. The wheat and tobacco lands are deteriorating. This cannot be due solely to a loss of plant food from the soil, for there is undoubtedly a change of texture of the soil, very apparent to the eye, which must change the relation of the soil to the circulation of water and to crop production. What these changes are which take place in the soil, must be fully investigated and must be well understood before the most intelligent methods can be proposed for the recovery and improvement of the lands.

The fertile terraces bordering the rivers of Southern Maryland are very level and very uniform in appearance. They extend about half a mile inland from the rivers. The soil is a fine grained loam and the subsoil a yellow clay loam. It would be classed as a good strong wheat soil, very easily worked and naturally very fertile and capable of the highest state of cultivation. They are similar in appearance to the "ridge lands" of the south. Recently the fertile valley lands along the B. & O. R. R., between Baltimore and Washington, (heretofore considered part of the Potomac formation,) as well as other lands in the vicinity of Baltimore, have been classed with the Columbian terrace formation, but these localities are not represented in our type samples.

The barren clay hills crossing the State in a broad belt from Washington, along the two railroads, to the Delaware line, belonging to the Potomac formation, have not been sampled.

The fertile soils of the Frederick and Hagerstown Valleys, formed by the disintegration of the Trenton limestone, are very heavy, red clay, well suited to grass and wheat, They are much stronger than the wheat lands of Southern Maryland. It takes a strong, heavy soil for grass and these are naturally good grass lands. We have a number of samples from different localities but not enough to make a satisfactory type sample.

The Triassic red sandstone covers a considerable area to the north and south of the limestone formation in the Frederick valley, with a dark, indian red, heavy clay soil. It is very productive but is not so safe or certain as the limestone soil. Like the limestone soil, it is greatly benefited by an application of lime.

The Helderberg limestone (cement rock) forms a small area of fertile hill and valley lands west of Hagerstown. The subsoil is a strong yellow clay, naturally well drained, and capable of a high state of cultivation. The land is well adapted to grass and wheat. The soil appears very uniform in texture and the type sample is considered fairly satisfactory.

The Catskill formation gives a very strong soil, well suited to both grass and wheat. It has a very characteristic dark red color.

The other formations are found in narrow belts forming the hills and mountain ranges, and, so far as I have seen, they are generally very poor and stony. There is often no perceptible difference between the soil and subsoil of these mountain formations, and where they cannot be distinguished, a sample is taken down to 12–18 inches and classed with the subsoils.

A description of the soils and subsoils which have been used to make up the type samples.

PINE BARRENS.

276. Type sample from the following localities:

209. Coarse yellow sand and gravel overlying neocene at Cove Point, three miles north of Drum Point.
210. Coarse yellow sand from bluff at Jones' wharf, Patuxent River.

TRUCK LAND.

283. Type sample of SOIL *from the following localities:*

144. Sandy soil from Patuxent, near Governor's Bridge. Naturally rather poor and unproductive but would make good truck and is typical watermelon land.
167. Sandy soil from a peach orchard at Mitchellville.
170. Soil of light lands west of Hall's Station. From the farm of J. Berry. Very characteristic truck land and of considerable area here.
267. Soil of truck land from farm of J. Birch, South River Neck.
269. Sandy soil of truck land, South River Neck.
271. Soil of truck land east of Hill's Bridge.

284. Type sample of SUBSOIL *from the following localities:*

145. Sandy subsoil from near Governor's Bridge. Under 144.
158. Subsoil of pine land on the "Ridge road" near Cheltenham. A compact red sand which should make good truck land. There is a large area of this land here, probably of Lafayette or possibly of neocene origin.
166. Subsoil from B. D. Mullikin's farm, between Hall's Station and Mitchellville. Characteristic truck land of that region, showing green grains of glauconite and of undoubted eocene origin.
169. Subsoil from peach orchard at Mitchellville, from under 167.
171. Subsoil of light lands west of Hall's Station, under 170.
268. Subsoil truck land, from under 267, from the farm of J. Bir ch South River Neck.
270. Subsoil of truck land, from under 269, South River Neck.
272. Subsoil truck land, from under 271, east of Hill's Bridge.

These soils and subsoils are undoubtedly of eocene origin except 158, and possibly 269 and 270, which were far down on the Neck and may be of more recent origin.

Tobacco Land.

285. Type sample of soil *from the following localities:*

145. Soil from Chas. W. Sellman's farm near Davidsonville. Rather light for wheat but makes good tobacco and corn.

161. Loam soil from J. H. Sasscer's farm near Upper Marlboro. A deep loam, lying rather low and much lighter than the best wheat lands. It is a fair type of the tobacco lands of Marlboro district, but is rather heavy for tobacco, making rather a heavy, coarse leaf. It is heavier than the Nottingham or Chaneyville tobacco lands Wheat, on this land, is inclined to go to straw and not produce much grain.

163. Soil of H. H. Sasscer's tobacco land, North Keys. Considered rather heavier than the best type of Nottingham tobacco land. It makes a very fine grade of tobacco.

255. Loam soil from W. H. Hopkins, Bristol. Light in texture and a very fine quality of tobacco land. Considered very fertile but rather light for wheat.

257. Soil of tobacco land from Fred. Sasscer's farm, Upper Marlboro.

259. Soil of tobacco land from the river terrace at Nottingham. The soil is coarser than most of the river terraces examined. This grade of soil appears to be of rather small area. The terraces extend about half a mile inland from the river and produce a fine quality of tobacco.

261. Soil from a farm near Chaneyville. It is considered the very finest grade of tobacco land.

263. Soil of a fine grade of tobacco land near Nottingham.

265. Soil of a very fine type of tobacco land from the farm of J. F. Talbott, Chaneyville.

286. Type sample of subsoil *from the following localities:*

Samples 148, 162, 164, 256, 258, 260, 262, 264, 266, from under the soils just given, and in the corresponding order.

These soils and subsoils are of neocene origin or formed of neocene material, except 259, 260, 263, 264. Diatoms were found in most of the subsoils. The finest tobacco lands are lighter in texture than the best wheat lands.

Wheat Land.

279. Type sample of SOIL *from the following localities:*

140. Loam soil from near Davidsonville, fairly representing the wheat lands of this locality. It appears somewhat light for wheat, and is not considered as productive as it was years ago. It does not produce the clover crops it once did, which were such an excellent preparation for wheat. The lands have deteriorated. The finest wheat lands now are the hill lands where this loam has not accumulated, or has been removed by subsequent washing, leaving exposed a yellow clay loam like 142.

154. Clay soil from J. H. Sasscer's farm near Upper Marlboro. Very fine wheat land, similar to the Davidsonville and West River lands. Too heavy for tobacco, the plant being sappy and curing green. These lands are of considerable area around Marlboro, extending up nearly to Mitchellville on the east of the railroad, and forming the bottom lands and hills, west of the Western Branch of the Patuxent, but becoming much lighter in texture south of Marlboro.

178. Clay soil at the base of the neocene, at Herring Bay. Good strong wheat land, very similar to the preceding localities.

183. Soil of wheat land from James Chapman, Pope's Creek. This land carries a good grass sod.

249. Soil of wheat land from J. F. Talbott, Chaneyville.

251. Soil of the fertile wheat lands of West River.

253. Loam soil from Mt. Zion. Very characteristic wheat land, similar to those of Davidsonville and West River.

280. Type sample of SUBSOIL *from the following localities:*

141. Loam subsoil from under 140, from near Davidsonville. It has good body but not the consistancy of the next sample. It fairly represents the lands around here where washing has not occurred. The loam is from two to four feet deep.

142. Yellow clay subsoil from under the above, taken in a road cut. This forms the very best wheat land when exposed. It has the very characteristic color and texture of the best wheat lands in Southern Maryland.

155. Clay subsoil of wheat land from under 154, from the farm of J. H. Sasscer, near Upper Marlboro.

156. Yellow clay subsoil under the "gravelly lands" of Rosaryville. This is undoubtedly neocene or neocene material. A fair quality of diatomaceous earth was found in a road cut near by, directly underlying this and gradually passing from the white earth into the yellow clay above. The country is covered generally with a thin layer of fine gravel, which is hardly noticed in cultivated fields and is often absent. The gravel extends down into the undisturbed clay and is probably part of the same formation, although there may be a light coating of Lafayette here, made out of the neocene material. The lands make a very fine quality of tobacco but are generally too light for wheat. When this clay is exposed without the gravel, however, it makes a very fine wheat land. On Mr. Holloway's place, between Rosaryville and Woodyard, and near where this sample was taken, they made a very fair quality of brick some years ago from the subsoil of the wheat field.

179. Clay subsoil of the wheat lands of Herring Bay, from under 178.

180. Yellow clay subsoil from over diatomaceous earth, from a bluff three miles north of Plum point.

184. Yellow clay subsoil of wheat land, from under 183, from the farm of James Chapman, Pope's Creek.

245. Subsoil f wheat land opposite the church at Davidsonville. It is in a fine state of cultivation.

246. Subsoil of wheat land about one half mile west of Davidsonville.

247. Subsoil of wheat land, now in grass, from the farm of James Iglehart, Davidsonville.

248. Subsoil of wheat land from the farm of P. H. Israel, Davidsonville.

250. Subsoil of wheat land from the farm of J. F. Talbott, Chaneyville. From under 249.

252. Subsoil of wheat land, from under 251, South River.

254. Subsoil of wheat land, from under 253, Mt. Zion.

River Terrace.

277. *Type sample of* SOIL *from the following localities:*

198. Loam soil from a wheat field opposite Benedict.

200. Loam soil from a corn field below St. Mary's. This soil is naturally fertile and is capable of great improvement. An excellent wheat soil.
202. Loam soil from Mr. Broome's wheat land, St. Mary's.
204. Loam soil from a wheat field opposite St. Mary's.
206. Loam soil from Clifton Beach. Good wheat land.

278. Type sample of SUBSOIL *from the following localities:* Samples 199, 201, 203, 205, 207, are subsoils from under the above soils, given in the same order.

HELDERBERG LIMESTONE.

287. Type sample of SOIL *from the following localities:*
221. Soil from near Hancock. Very fertile grass and wheat land.
222. Soil from near Hancock.

288. Type sample of SUBSOIL *from the following localities:*
220. Very fertile grass and wheat land two miles west of Hancock. No change in 18 inches.
223. Subsoil near Hancock.
224. Characteristic yellow subsoil of the Helderberg limestone, from a wheat field two miles west of Hancock. Contains many small fragments of undecomposed rock.
225. Subsoil from near Cumberland. Naturally rather poor but has good body and is very fertile where improved.

CATSKILL.

238. Type sample of the Catskill formation, from near Mt. Savage. Good strong land for grass and wheat. Has a characteristic, dark red color.

ORISKANY.

290. Type sample of Oriskany from the following localities:
226 and 227, from near Cumberland, and 228, from Hancock. The formation is not very uniform in texture. The localities visited have rather a fine textured soil, naturally poor but capable of some improvement. The formation occurs only in narrow belts capping hills and mountains, and is not of much extent in the State.

Chemung, Hamilton, Niagara and Clinton.

289. *Type sample from the following localities:*

234. Subsoil of the Hamilton shale, from near Mt. Savage. Naturally very poor but capable of some improvement as it has good body.
235. Hamilton shale, from Cumberland. Poor lands—mostly thin mountain pastures.
236 and 237, Chemung from two localities near Mt. Savage. Naturally rather poor land.
239. Niagara from near Cumberland. Poor but has good body and is capable of some improvement.
240. Clinton shale from near Cumberland. Lands naturally poor but have good body.

These formations appear so much alike in texture and agricultural features that they are all included in the one type. They are nearly all hill and mountain pastures, naturally poor and not capable of great improvement, except as garden spots and at great expense. The soil or rather subsoil, for there is little or no difference, is a very fine grained, powdery material, filled with small fragments of the original rock.

VI. Mechanical Analysis of the Type Soils.

The soils of these type formations differ so much in texture that the difference is quite apparent to the eye. Some are coarser than others, the grains are larger and there are fewer of them in a given weight of soil. The first thing done, in the examination of the soil, was to make a mechanical analysis by separating the grains into groups, according to size. The approximate number of grains in each group was then calculated and this shows how much the empty space in the soil has been divided up and, relatively, how fast water will move through the different soils.

For the greatest accuracy, the grains should be separated into a large number of groups, so that all the grains in each group shall be very nearly of the same size, but the analysis takes so long that we have used only eight groups. The separations were made substantially after Johnson and Osborn's "beaker method." We have taken .0001 mm. as the lowest limit of size of the grains of clay, based on many measurements we have made. The clay group has relatively wide limits (.005–.0001 mm.) but we have not attempted a further separation than this. A millimeter (1 mm.) is equivalent to about 1-25th of an inch, so that the smallest grains of clay are about 1-25400 inch or .0000039 inch in diameter.

Table 4, gives the results of the mechanical analysis of the type samples of the subsoils of the five formations in Southern Maryland. The analyses and calculations based on the other type samples will not be completed in time for this report.* The subsoils have been taken up first, as the texture of the subsoil is more important in determining the nature of the land and its relation to the water supply of crops than that of the soil itself.

TABLE 4:—MECHANICAL ANALYSES OF TYPE SUBSOILS.

Diameter. *mm.*	Conventional names.	276. Pine barrens.	284. Truck.	286. Tobacco.	280. Wheat.	278. River terrace.
2–1	Gravel	†4.87	0.68	1.36	0.00	1.60
1–.5	Coarse sand	9.15	2.89	2.13	0.42	1.51
.5–.25	Medium sand	38.37	21.85	7.78	1.81	4.15
.25–.1	Fine sand	33.28	25.82	16.57	8.59	4.84
.1–.05	Very fine sand	3.52	18.38	19.83	32.06	8.54
.05–.01	Silt.	3.47	9.48	25.41	23.65	44.92
.01–.005	Fine silt	1.55	3.37	4.52	6.77	5.78
.005–.0001	Clay	3.75	15.30	17.95	22.55	25.85
		97.96	97.77	95.55	95.85	97.19
Organic matter, water, loss..		2.04	2.23	4.45	4.15	2.81

† This includes 1.81 per cent. larger than 2*mm.* in diameter.

NOTE.—Each of these type samples is made up of samples from a number of localities in each soil formation.

The results in this table are confusing from the mass of figures, and from the fact that each group has to be given a special value, depending upon the size of the soil grains which it contains; a per cent. of clay having far more value than an equal amount of gravel. From this table alone it would be difficult to judge of the texture of the soils.

VII. APPROXIMATE NUMBER OF GRAINS PER GRAM OF SOIL.

From the results in Table 4 we have calculated the approximate number of grains of sand and clay in one gram of the subsoils, as

*This matter has since been completed and will be given in an appendix.

given in Table 5. These figures are, of course, only approximate and the numbers are far beyond our comprehension. They may be used relatively, however, in comparing one soil with another.

TABLE 5:—APPROXIMATE NUMBER OF GRAINS PER GRAM OF SUBSOIL.*

Diameter. *mm.*	Conventional names.	276. Pine barrens.	284. Truck.	286. Tobacco.	280. Wheat.	278. River terrace.
2–1	Gravel	7	1	3	0	3
1–.5	Coarse sand	160	50	38	7	26
.5–.25	Medium sand	5 356	3 056	1 114	258	583
.25–.1	Fine sand	45 700	35 530	23 320	12 050	6 701
.1–.05	Very fine sand	61 380	321 200	354 500	571 200	150 200
.05–.01	Silt	945 900	2 589 000	7 101 000	6 588 000	12 340 000
.01–.005	Fine Silt	27 030 000	58 880 000	80 790 000	120 700 000	101 600 000
.005–.0001	Clay	1 664 000 000	6 806 000 000	8 170 000 000	10 230 000 000	11 570 000 000
		1 692 088 503	6 867 828 837	8 258 269 975	10 357 871 515	11 684 097 513

* There are about 453 grams in one pound.

It will be remembered that the texture of the soil is determined by the size and, therefore, by the number of grains per unit weight or volume of soil. In this table it will be seen that the number of grains in the fine "silt" and "clay" groups so far exceed the number in all the other groups combined, that they, and especially the clay, actually determine the extent of subdivision of the empty space in the soil. The other groups may be neglected, for practically, the effect of the gravel and sand, is only to diminish the amount of clay per unit weight or volume of soil. The amount of clay is, therefore, a very important factor in any soil as it practically determines the subdivision of the empty space and the texture of the land.

TABLE 6:—TOTAL NUMBER OF GRAINS IN ONE GRAM.

(*Summary of Results in Table* 5.)

276......	Pine barrens............	*(2)	1 692 000 000
284......	Truck..................	(8)	6 868 000 000
286......	Tobacco............. ..	(9)	8 258 000 000
280......	Wheat	(14)	10 358 000 000
278......	River terrace.....	(5)	11 684 000 000
....	Limestone (grass land)...	(1)	24 653 000 000

*Number of localities represented.

The summary of the results in Table 6 places the soils at once in their true agricultural relation. It suggests also a method for the classification of soils.

From the mechanical analysis of the samples which were used to make up these type samples, and perhaps of a large number of other soils of known agricultural value, it should be possible to determine the smallest and the largest number of grains per gram of soil where these different crops could be successfully grown. For example, no crop can be successfully grown, except under highly artificial conditions of manuring with organic matter, or by irrigation, on a soil having so few as *one thousand seven hundred million* grains per gram. Good market truck is grown on a soil having *six thousand eight hundred million* grains. Now what is the limit between these two figures where the soil becomes too light for market truck? Good wheat is grown on a soil having *ten thousand million* grains per gram, and this must be near the limit of profitable wheat production, for *eight thousand million* grains per gram gives a soil rather too light for wheat, but well suited to tobacco. A soil having *ten thousand million* grains per gram is too light for grass, which thrives on a limestone soil having *twenty-four thousand million.* Our type soils should, therefore, show the range for the profitable production of a given crop. We should be able also from the mechanical analysis of an unknown soil to give it its true agricultural place by reference to these established soil types.

It is not to be inferred from these statements that wheat cannot be grown on a soil having so few as *one thousand million* grains per gram. This number represents merely the skeleton, or framework, of the soil. As we shall see later, this may be so filled in and modified by organic matter as to enable it to support a good wheat crop, but at such an expense as to put it far outside the limit of profitable culture. This is a matter of judgment and experience. The soil types give only the skeleton structure of the soil.

Nor is it to be inferred that wheat may be grown on all soils having *ten thousand million* grains or more per gram with equal success, for the relation of these soils to water, upon which the cropping depends, is a matter not only of how much the space within the soil is subdivided, that is, how many grains there are, but depends also upon the way these grains are arranged. We will develop this idea further, when we come to speak of the cause of the deterioration of lands and of their improvement.

VII. Approximate Extent of Surface Area per Cubic Foot of Soil.

We are able, from the foregoing results, based on the mechanical anlysis of the soils, to calculate the approximate extent of surface area of the grains of clay and sand in a given weight or volume of soil.

A solid block of granite, one foot square and one foot high, would have six square feet of surface area, but when this cube of solid rock disintegrates, forming or leaving a cubic foot of soil, half of the rock is dissolved and carried off and what remains is split up into a vast number of separate grains of sand and clay. If a soil were made up of fragments as large as this cubic foot of rock, then, even if the proper water supply could be maintained in the soil, it would be impossible for our staple crops to get their needed food supply. The soil moisture and the roots themselves can only dissolve food material from the surface of the rock. The rock is exceedingly insoluble and the amount of plant food which could be dissolved and extracted from six square feet of surface by water or roots, would be exceedingly small and entirely insufficient for the needs of any of our staple crops.

The soil, however, resulting from the disintegration of such a rock has an enormous extent of surface area if all the surface on the separate grains of sand and clay be considered. Table 7 gives the approximate extent, in square centimeters, of the surface area in one gram of our type subsoils and of a limestone subsoil from Frederick Valley. Table 8 shows the approximate number of *square feet* of surface area in *one cubic foot* of soil.

TABLE 7:—SURFACE AREA (*sq. cm.*) PER GRAM OF SUBSOIL.

		276.	284.	286.	280.	279.	......
Diameter. *mm.*	Conventional names.	Pine barrens.	Truck.	Tobacco.	Wheat.	River terrace.	Limestone.
2–1	Gravel	0.5	0.1	0.2	0.0	0.2	0.0
1–.5.	Coarse sand	2.8	1.0	0.7	0.1	0.5	0.0
.5–.25	Medium sand	23.6	13.5	4.9	1.1	2.6	0.1
.25–.1	Fine sand	43.9	34.1	22.4	11.6	6.4	0.4
.1–.05	Very fine sand	10.8	56.7	62.5	100.9	26.5	7.6
.05–.01	Silt	26.7	73.1	200.7	186.2	348.7	221.3
.01–.005	Fine silt	47.7	104.1	142.8	213.2	179.5	344.3
.005–.0001	Clay	339.8	1387.0	1668.0	2089 0	2360.0	5000.0
		495.8	1669.6	2102.2	2602.1	2924.4	5573.7

TABLE 8:—SQUARE FEET OF SURFACE PER CUBIC FOOT OF SUBSOIL.

276	Pine barrens....	23 940 square feet.
284......	Truck..........	74 130 " "
286......	Tobacco.........	84 850 " "
280	Wheat..........	94 540 " "
278......	River terrace....	106 200 " "
		(2.3 acres.)
....	Limestone.......	202 600 square feet.
		(158 000 acres.)

It will be seen that there are upwards of 24,000 square feet of surface area in a cubic foot of the subsoil of the pine barrens, no less than 100,000 square feet, or 2.3 acres, of surface area in a cubic foot of the subsoil of the river terrace, and 158,000 square feet of surface area in a cubic foot of the limestone subsoil.

These figures seem vast, but they are probably below, rather than above, the true values on account of the wide range of the diameters of the clay group, as given in the table. This gives an enormous area for the roots and soil moisture to act on for the extraction of plant food from the mineral elements of the soil. Instead of the few square feet offered by the cube of granite, there are now several acres of surface area, for the roots to range over, in search of food and for the water to act on, in a single cubic foot of soil. This great extent of surface and of surface attraction, which has been described as potential in Section II., gives the soil great power to absorb moisture from the air, and to absorb and hold back mineral matters from solution. A smooth surface of glass will attract and hold, by this surface attraction, an appreciable amount of moisture from the surrounding air. A cubic foot of soil, having 100,000 square feet of surface, should be able to attract and hold a considerable amount of moisture from the air.

When a soil is only slightly moistened with water there will be nearly as much exposed water-surface as the surface of the soil grains themselves. The amount of energy or tension on such an extent of water-surface will be very great and it is this which enables a soil to draw up the large amount of water needed by the crop.

In all of these relations, the extent of surface gives the soil a certain strength and value which must have an important bearing on crop production and distribution.

IX. The Circulation of Water in these Type Soils.

We have shown that the number of grains per gram, places these type soils in their true agricultural relation. We have now to show the reason for this in the difference in their relation to the circulation of water, and the ease with which a definite quantity of water can be supplied to a given crop.

We will assume that the grains in all the soils have the same mean arrangement, then the relative rate of circulation, other things being equal, will depend upon how much space there is in the soil and upon how much this space is subdivided.

For the reasons which have already been given, we have not been able to determine the amount of space in the soils which were used to make up the type samples. The determinations require much time and great care to remove a definite volume of soil from the field, and this must be made the subject of some future investigation. From our work in South Carolina on similar soils, which has been referred to, we have assumed the per cent. of empty space in each of the soil types, given in the following tables. These values, therefore, are not exact determinations, but are thought to be approximately correct. It is important to observe that the coarser soils have less space and, consequently, when this space is completely filled with water, the sandy soils will contain less water than the clay soils. In a cubic foot of the sandy soils there is considerably less than half a cubic foot of empty space; in the same volume of the clay soils there is *over* half a cubic foot of space for water to move in. This difference in the amount of space in the different soils, gives rise to an important modification of the relative rate of circulation, when the soils are saturated, and when they are short of saturation.

The empty space in agricultural soils is hardly ever completely filled with water. The most favorable amount of water in the soil, for growing plants, as Hellriegel and others have shown, is from 30 to 50 per cent. of the water-holding capacity of the soil. As a light sandy land has less space and will hold less water than a clay soil, the most favorable amount of water for vegetation will be less than in a clay soil. We have repeatedly found in actual determinations, less water in light lands than in heavy clay soils, and it is a matter of observation and experience that light lands are drier than heavy clay soils.

The reason for this follows from the fact that water circulates more freely in these light soils, by reason of the fewer grains and the less amount of subdivision of the empty space, and after a moderate rain the water passes down more readily into the lower depths of the subsoil.

After the excess of rainfall has passed down through the soils and, equilibruim is established, there will be less water in the light lands than in the clay soils. If, then, a definite quantity of water is required, by the crop in a given time, it can move up to the plant through the sandy soil more readily, but there is less *water-surface* in the light land to contract, that is, there is less force to pull the water up. These points are well brought out in the following calculations of the relative rate of circulation of water in these type subsoils.

If we assume in the first place, that all the soils contain the same amount of water, namely 12 per cent. (the most favorable amount in the wheat land,) the relative rate of circulation will be as follows:

No.	Soil.	Space.	Water-content.	Relative time.
276....	Pine barrens....	40 per cent.	12 per cent.	17
284....	Truck	45 " "	12 " "	43
286....	Tobacco	50 " "	12 " "	68
280 ...	Wheat..........	55 " "	12 " "	92
278....	River terrace....	55 " "	12 " "	100

If it takes 100 minutes for a quantity of water to pass down through a certain depth of the subsoil of the river terrace, the same weight of water could pass down through the subsoil of the truck land in 43 minutes, and through the subsoil of the pine barrens in 17 minutes. It could not move up so readily for there is less *water surface*, as we have shown, to contract and pull it up from below.

When equilibrium is established and the water is moving down with about the *same rate* in each of the subsoils, there will be about 6.5 per cent. in the subsoil of the pine barrens, 9 per cent. in the truck land and 12 per cent. in the subsoil of the river terrace, as follows:

No.	Soil.	Space.	Water-content.	Relative time.
276....	Pine barrens....	40 per cent.	6.6 per cent.	102
284....	Truck	45 " "	9.0 " "	102
286....	Tobacco........	50 " "	10.5 " "	102
280....	Wheat.	55 " "	11.7 " "	101
278....	River terrace...	55 " "	12.0 " "	100

This would be about the relative amount of water found in these subsoils some time after rain. When the subsoil of the river terrace contains 12 per cent. of water, that of the pine barren would contain about 6.5 per cent., that of the truck land, 9 per cent.

The interesting question suggested above, comes up here again. If the rate of circulation of water through the light truck land with 9 per cent. of water present in the subsoil, is the same as in the wheat soil of the river terrace with 12 per cent. of water, (the most favorable amount for wheat), then why are not the light truck lands as good for wheat as the other? And the explanation given above is only made clearer through these tables, that while gravity acts with a constant force, *with* surface tension, to pull the water down, surface tension alone has to pull the water up to the crop *against gravity;* and there is less surface tension, less contracting power, less force, to pull up a given weight of water in a given time in the light land than in the other. The wheat crop would suffer on such a soil in a warm, dry spell, when it had to depend on water being supplied it from below.

We have shown that there is less space in the light truck land than in the wheat soils, but the soil grains being larger, there are fewer of them, and the space is not divided up so much. Each separate space is larger and, when the soil is short of saturation, the water moves faster.

If however the soils are fully saturated, the volume of empty space has an important value in retarding the rate of movement. There is less volume of space in the light lands, less water can be crowded into it than in the wheat soils, and so, when the spaces in the soils are fully saturated, the rate of movement will be relatively slower than in the wheat soils.

The relative rate of movement of water through these different subsoils when all the space is filled with water, will be as follows:

No.	Soil.	Space.	Water-content.	Relative time.
276..	Pine barrens..	40 per cent.	20.10 per cent. (Sat.)	63
284..	Truck........	45 " "	22.41 " " "	120
286..	Tobacco	50 " "	27.42 " " "	103
280..	Wheat	55 " "	31.55 " " "	92
278..	River terrace.	55 " "	31.55 " " "	100

If all the space is filled with water, as assumed in Table 9, the subsoils will contain, respectively, 25, 28, 31, 33, and 33 pounds of water per cubic foot. If a given quantity of water passes down through a depth of saturated subsoil of the river terrace in 100 minutes, it would take about 120 minutes for the same quantity of water to go down through the same depth of the saturated subsoil of the light truck land. This probably explains a matter of common observation and experience, that crops on light sandy lands are more injured in excessive wet seasons than crops on heavier soils. The excess of water cannot be removed so fast by the light lands, when saturated, as in the heavier soils.

There are other interesting lines of thought, and explanations of other matters of common observation and experience, suggested by this line of reasoning, which may be followed out at another time as the limits of this report allow of only a concise narrative account of the work and a very general statement of the application of the results.

X. The Improvement of Soils.

When we consider that desserts are barren only from the lack of water and that where water is supplied they become fertile and productive as other lands; and when we consider the immense crops raised in dry and arid countries by irrigation as well as the difference in the yield of crops in our own state, in wet and in dry seasons, and other evidences which will be published at another time, we are forced to the conclusion that vegetation is very largely dependent for its developement and growth upon a proper water supply, and that the whole art of cultivation and manuring is based upon the possible control of the water supply within the soil.

We have shown the principles upon which this control is based; we come now to an application of these principles to the improvement of soils.

The agricultural lands of this state have generally good surface drainage. They have a small quantity of organic matter which is fairly uniform in amount in the soils of the different soil formations. If such a soil is shown by a mechanical analysis to have not less than *ten thousand million* grains per gram, it has the structure, or frame work, for a good wheat soil and should be classed as such. If it does not produce good wheat crops, or if it has deteriorated from a more fertile condition, there may be some change in the structure of the soil through a change in the arrangement of the soil grains.

The case must be studied as a physician considers the condition of a sick person; a diagnosis must be made to determine the cause of the trouble. The symptoms both of the soil and of the crops must be carefully studied. If the soil is rather close and too retentive of moisture, the plants are large and sappy and give a small yield of fruit or seed in proportion to the size of the plant and the amount of food material gathered by the plant from the atmosphere and soil. The crop is also inclined to be late it maturing.

If the soil is dry and leachy, the plants are small and give a small yield, but the yield is relatively larger in proportion to the food material that has been stored up.

Other symptoms, besides this relation of the yield of grain and fruit to the size of the plant, that is, to the amount of food material stored up by the plant, offer evidence as to the condition of the soil and the changes needed for its improvement, such as the vigor of the plant, the way it develops and grows, the diseases and insect ravages to which it is subject, and the influence of wet and dry seasons on the crop production.

The cotton crop at the South is very sensitive to these conditions of environments. The wheat crop more readily adapts itself to the conditions under which it is grown, and is, therefore, not so sensitive or reliable for showing up these soil conditions.

There is need of an instrument, or a method, to show the actual rate with which water moves both up and down within the soil in its natural position in the field, and such a method must be devised, for the information is of great importance.

It has been shown how the relative rate of circulation of water may be calculated from the mechanical analysis of the soil. If this calculated rate could be compared with the actual rate of circulation in the soil in the field, it would indicate the relative arrangement of the soil grains, so that if we had such a method there would be no such necessity for studying the symptoms of the plant to tell in what direction, and how far, the conditions in a soil have departed from the typical conditions required by a given crop, or natural to the soil formation.

If the rate of circulation of water within the soil is shown, by actual observation or by its effect upon plants, to be slower than the rate calculated from the mechanical analysis, and slower than the rate of circulation in the typical soil for that crop, the texture of the soil may be changed by changing the arrangement of the soil grains. The smallest grains may be drawn closer to the larger ones, making some of the spaces larger and others exceedingly small. Lime, kainite and phosphoric acid seem to have this effect, as their continued use makes the soil more loamy, looser in texture, and less retentive of moisture.

Many of our agricultural lands need improvement in the other direction, they need to be made closer in texture and more retentive of moisture. We have found that ammonia, the caustic alkalies, carbonate of soda, and probably many other substances, possibly organic substances in general, tend to prevent this flocculation and to push the smaller grains further apart, making the spaces within the soil of a more uniform size and thus retarding the rate of circulation of the soil moisture. We cannot say what practical value this will have in its application to agriculture until more work has been done.

When a solution of organic matter comes in contract with lime, kainite, acid phosphate, and with certain soils, the organic matter is precipitated from solution in light, bulky masses, and these masses may fill up the spaces within the soil with solid matter which not only retards the rate of circulation of water downward by gravity, but, by increasing the extent of water-surface within the soil, it also assists in pulling water up from below.

If so much organic matter is added to the soil that it cannot be curdled or precipitated from solution, it may be injurious in the soil by reducing the surface tension of the soil moisture, the force which draws the water to the plant as needed. The judicious use of lime, kainite or acid phosphate, along with the organic matter, will insure the precipitation of the organic matter from solution and thus give a value to the application which it would not otherwise have had.

This gives a value to stable manure, out of all proportion to the amount of plant food which it contains. Lime, also, either alone or when acting with organic matter, has a distinct value for all classes of land. The nitrogenous matters in the stable manure, and in other organic matters, would determine the value as a fertilizer, for it is only the nitrogenous compounds which are so easily precipitated from solution by the mineral matters of the soil and of fertilizers. If the carbohydrates, such as starch, sugar and woody fibre, could be as readily precipitated from solution in light, bulky masses, by lime and the mineral matters of the soil, then sawdust or other organic refuse containing little nitrogen, would have nearly the same fertilizing value as the more expensive nitrogenous materials.

The whole history of plat experiments shows that it is not the plant which is to be manured for, but the soil conditions must be changed to produce the plant.

The corn plant on one soil requires potash, on another soil, phosphoric acid, on another soil, nitrogen, and again on another soil a combination of two or more of these fertilizers. On the whole, there is no such fertilizer in our State for wheat as lime, used alone or acting with organic matter.

Plat experiments frequently give a larger yield when lime, salt or plaster is used, and even when nothing at all has been added to the soil, than when the more expensive plant foods have been used. Especially when acid phosphate or potash has been used alone, the yield is often smaller than where nothing has been added to the soil.

Under ordinary conditions, our crops do not require special plant foods, but they all have somewhat different habits of growth and development and can best gather food under somewhat different physical conditions. We have seen how these different fertilizing materials change the physical conditions in the soil.

This opens up a new and wide field for investigation in the study of the physical conditions of the soil in their relation to plant growth and developement, and the effect thereon of the different fertilizers and manures. It will be through this study that the true theory of fertilization will be seen, and an interpretation and added value be given to the immense amount of chemical data, which has accumulated, relating to the soil.

Correction:—Through an oversight, part of the explanation of the phenomenon of flocculation on page 258 was transposed. It should read as follows: If the potential of the surface particle of water is less than of a particle in the interior of the mass of liquid, there will be surface tension, and the two grains will come together and be held with some force, as their close contact will diminish the number of surface particles in the liquid. If, on the other hand, the potential of the particle on the surface of the liquid is greater than the potential of a particle in the interior of the liquid mass, the surface will tend to enlarge, and the grains of clay will not come close together, as their close contact will diminish the number of surface particles in the liquid around them.

M. W.

APPENDIX.

Since the main part of my report was written, I have been able to secure the services of Mr. F. P. Veitch and Mr. J. B. Latimer, graduates of the class of 1891 of the Agricultural College. Mr. Veitch has completed the mechanical analysis of our type subsoils, which enables me to present the results here, with a short discussion.

The mechanical analysis of these type subsoils, given in Table 13, is based upon the "fine earth," or material smaller than 2 *mm.* in

TABLE 10:—MECHANICAL ANALYSIS OF TYPE SUBSOILS.

Diameter. *mm.*	Conventional names.	276. Pine barrens.	284. Truck.	286. Tobacco.	290 Oriskany.	280. Wheat.	278. River terrace.	282. Triassic.	238. Catskill.	289. Shales.	288. Helderberg limestone.
2–1	Gravel	*4.87	0.68	1.36	0.64	0.0	1.60	0.00	0.00	0.05	†1.34
1–.5	Coarse sand	9.15	2.89	2.13	0.81	0.42	1.51	0.23	0.11	0.16	0.33
.5–.25	Medium sand	38.37	21.85	7.78	3.50	1.81	4.15	1.29	0.42	0.80	1.08
.25–.1	Fine sand	33.28	25.82	16.57	23.97	8.59	4.84	4.03	2.63	2.01	1.02
.1–.05	Very fine sand	3.52	18.38	19.83	34.76	32.06	8.54	11.57	11.35	6.70	6.94
.05–.01	Silt	3.47	9.48	25.41	10.03	23.65	44.92	38.97	40.23	31.63	29.05
.01–.005	Fine Silt	1.55	3.37	4.52	3.03	6.77	5.78	8.84	10.90	14.24	11.03
.005–.0001	Clay	3.75	15.30	17.95	20.30	22.85	25.85	32.70	33.32	39.36	43.44
		97.96	97.77	9[illegible]55	97.04	95.85	97.19	97.63	98.96	94.91	94.23
Organic matter, water, loss:		2.04	2.23	4.45	2.96	4.15	2.81	2.37	1.04	5.09	5.77

*This includes 1.81 per cent. coarser than 2 *mm.*

†This includes 0.82 per cent. coarser than 2 *mm.*

diameter. Three of these subsoils were not thoroughly disintegrated, but contained small fragments of rock, which were separated out and weighed, the remaining fine earth being used for the mechanical analysis. The samples contained the following per cent. of coarse and of fine material.

	290	238	289
	Oriskany.	Catskill.	Shales.
Coarser than 2 *mm.*	5.80	21.28	17.23
"Fine earth"	94.20	78.72	82.77

We have not, as yet, attempted to study the effect of these fragments of rock upon the relation of the soils to the movement of water, but have confined ourselves to the simpler study of soils having no coarse fragments, and we will, therefore, disregard this coarse material for the present, and treat the soils as though composed only of the fine earth. It may well be, that in some localities disintegration has gone further than where these samples were taken, and that these same soil formations there contain no coarse fragments of the undecomposed rock. Our results should apply directly to such a soil.

TABLE 11:—APPROXIMATE NUMBER OF GRAINS IN ONE GRAM OF SUBSOIL.

276.	Pine barrens.	1 692 000 000
284.	Truck.	6 868 000 000
286.	Tobacco.	8 258 000 000
290.	Oriskany.	9 154 000 000
280.	Wheat.	10 358 000 000
278.	River terrace.	11 684 000 000
282.	Triassic red sandstone.	14 736 000 000
238.	Catskill.	14 839 000 000
289.	Shales (Hamilton, &c.)	18 295 000 000
288.	Helderberg limestone.	19 638 000 000
....	Trenton chazy limestone.	24 653 000 000

Table 11 gives the approximate number of grains of sand and clay in one gram of these type subsoils, and the results confirm what has been stated before, that the soils thus arranged are in the order of their relative agricultural value.

The Oriskany formation is of very small agricultural importance, as it has such a small area in the State, occurring in narrow belts, the widest being hardly more than a mile across. It has a place in the table between the tobacco and wheat soils of Southern Maryland.

The Triassic red sandstone and the Catskill formations are shown to have about the same structure. The soils themselves are very similar, and, except for their distinct geological and geographical positions, they should be grouped as a single soil type. The Catskill formation covers a considerable area in the valley between Sideling Hill and Town Hill Mountains, and again between the Great Savage Mountain and the Meadow Mountain, with a very narrow belt near Dan's Mountain, between Mt. Savage and Cumberland, where our single sample of the formation was obtained. This is an important soil formation, which should be more carefully studied, and of which more samples should be taken. From the general appearance of the land, as seen from the train in passing, there does not seem to be as much undecomposed rock in the soils of these wider areas as is contained in the sample, which is given here. I should estimate that there are about 320 square miles of this Catskill formation in Western Maryland, and about the same area of the Triassic red sandstone to the north and south of the Frederick Valley.

The Hamilton and Chemung shales have their widest exposure around Hancock and on either side of the Polish Mountain, covering perhaps 125 square miles. The Clinton and Niagara shales occur in very narrow ridges, giving a much smaller exposure than this. The mechanical analysis of the type sample of these formations gives 39.36 per cent. of "clay," or, approximately, eighteen thousand million grains per gram. The samples contained many small fragments of rock, so far disintegrated that they went to pieces at once between the fingers, or when they were gently rubbed with the rubber pestle under water. As these fragments would so readily fall to pieces in handling, much of this was classed as "fine earth," and only 17.23 per cent. could be separated out as coarse material. I think that this type has not its true agricultural place in the arrangement of these tables, as the grains of sand and clay have evidently not the same arrangement as in a soil where the disintegration has been more complete and the grains are more evenly distributed. It was stated in a previous section that these soils were naturally poor, but had good body and could be improved. This table shows that they have good body, and it remains now to show how the actual conditions differ from the best conditions which should prevail in this type soil, and how the soils can best be improved. In other States, where these shales are more thoroughly decomposed, they make some of the most fertile lands. They should have a value not far below that of the Helderberg limestone.

There is but a small area of the Helderberg limestone in this State, occurring in several narrow belts crossing Western Maryland. The area of the whole formation is only a few square miles in extent. The formation gives a very fine grass and wheat soil. In the calculations which follow, I have used the Helderberg limestone as the strongest soil, and the best for grass and wheat of any of the types, not having sufficient samples from the Trenton limestone to establish a satisfactory type sample.

I must again urge, as in a former paragraph, that the number of grains of sand and clay give only the skeleton structure of the soil, and that this may be so filled in with organic matter as to greatly modify the physical properties of the soil. The amount of organic matter is assumed to be fairly constant for the different types, and is a matter of more importance in the study of local soils. It is important also to remember that the structure of the soil, and its relation to the circulation of water, is dependent not only upon how many grains there are per gram, but upon how these grains are arranged. In our calculations, we have assumed that they have the same mean arrangement in all the type soils; but this is evidently not so in regard to local soils, for we have suggested that the deterioration of soils is due largely to a change in the arrangement of the soil grains, changing the relation of the soil to the circulation of water. These type samples, however, represent more than this, for they are selected to represent the average, natural condition of these great soil formations.

The average, natural arrangement of the grains in these great soil formations must be determined to give an additional basis of comparison between the different types, but especially for the comparison of local soils, which may have departed, in one way or another, from the type conditions, through a re-arrangement of the grains of sand and clay. This is important in the study and classification of local soils.

It is quite possible to conceive of a brick clay or a tight pipe clay, having no more grains per gram than this Helderberg limestone. If a few drops of caustic ammonia was applied to the Helderberg soil, through which a certain weight of water was passing in a hundred minutes, the grains of soil would be re-arranged, and it would take several thousand minutes for the same amount of water to pass. On the other hand, a little lime water would make the soil more loamy, and hasten the rate of movement of water. We have thus a loam soil, a good clay soil, and an impervious pipe clay, out of the same soil, by a simple re-arrangement of the sand and clay. The arrangement of the grains has, therefore, an important bearing on the physical properties of the soil, but this is largely dependent upon local causes, which modify the conditions in the original soil formation.

From the results in these tables it would seem that the subsoil of good grass land would have not less than 30 per cent. of clay, or about *twelve thousand million* grains per gram, and good wheat land not less than twenty per cent., or about *nine thousand million* grains per gram; *provided*, these grains have a certain mean arrangement and that this skeleton structure contains an average amount of organic matter. It must be remembered that if either the arrangement of the grains or the amount and condition of the organic matter departs from the average condition of the soil, the physical condition of the local soil will depart from the typical conditions of the soil formation.

These type subsoils have the following approximate extent of surface area per cubic foot:

276. Pine barrens.	40	per	cent.	space.	23 940	square	feet.
284. Truck.	45	"	"	"	74 130	"	"
286. Tobacco.	50	"	"	"	84 850	"	"
290. Oriskany.	50	"	"	"	87 720	"	"
280. Wheat.	55	"	"	"	94 540	"	"
278. River terrace.	55	"	"	"	106 200	"	"
282. Triassic.	55	"	"	"	127 000	"	"
288. Helderberg limestone.	65	"	"	"	129 700	"	"
238. Catskill.	55	"	"	"	133 300	"	"
289. Shales (Hamilton, &c.)	60	"	"	"	142 700	"	"

The practical bearing of these results has been quite fully set forth in Section VIII. The Helderberg limestone has a place here before the Catskill and the shales, because we have given it a high percentage of empty space, higher perhaps than should have been given. It has, of course, the highest percentage of surface area per unit weight of any of these subsoils, but the larger amount of space lowers the percentage per unit volume of soil.

From the foregoing results, we have calculated the relative rate with which a given quantity of water would pass through an equal depth of these subsoils, under a constant force and with the same amount of water (12 per cent.) in each subsoil, taking the subsoil of the Helderberg limestone as a basis of comparison.

It would appear from results on next page that, with 12 per cent. of water present in all the subsoils, it will take only 8 minutes for a quantity of water to pass through the subsoil of the pine barrens, which would require 100 minutes to pass through the same depth of the subsoil of the Helderberg limestone. It will pass through the subsoil of the wheat land of the river terraces in Southern Maryland in about 49 minutes. It will move down more readily in these lighter soils from its own weight, but, as I have urged in a previous section, a given quantity of water could not be raised so readily to supply the needs of a growing crop, for there would be less exposed water-surface to contract, that is, there would be less force to pull it up.

No.	Soil.	Space.	Water-content.	Relative Time.
276.	Pine barrens.	40 per cent.	12 per cent.	8
284.	Truck.	45 " "	12 " "	21
286.	Tobacco.	50 " "	12 " "	33
290.	Oriskany.	50 " "	12 " "	35
280.	Wheat.	55 " "	12 " "	45
278.	River terrace.	55 " "	12 " "	49
282.	Triassic.	55 " "	12 " "	56
238.	Catskill.	55 " "	12 " "	58
289.	Shales (Hamilton, &c.)	60 " "	12 " "	81
288.	Helderberg limestone.	65 " "	12 " "	100

I have calculated the amount of water which should be present in these different subsoils for the rate of movement, due to a constant force, to be the same as in the subsoil of the Helderberg limestone, containing 12 per cent. of water.

No.	Soil.	Space.	Water-content.	Relative Time.
276.	Pine barrens.	40 per cent.	5.3 per cent.	101
284.	Truck.	45 " "	7.2 " "	101
286.	Tobacco.	50 " "	8.4 " "	102
290.	Oriskany.	50 " "	8.6 " "	101
280.	Wheat.	55 " "	9.4 " "	100
278.	River terrace.	55 " "	9.6 " "	100
282.	Triassic.	55 " "	10.0 " "	101
238.	Catskill.	55 " "	10.1 " "	100
289.	Shales (Hamilton, &c.)	60 " "	11.2 " "	100
288.	Helderberg limestone.	65 " "	12.0 " "	100

The relation of these different subsoils to water is as different as in the artificial conditions in green house culture. The difference is amply sufficient to account for the distribution of plants and for the known relations of these different soils to plant growth and development.

I have also calculated the relative rate with which water would move, under a constant force, through these different subsoils, if all the space within them was filled with water.

No.	Soil.	Space.	Water-content.	Relative Time.
276.	Pine barrens.	40 per cent.	20.10 per cent. (sat.)	74
284.	Truck.	45 " "	22.41 " " "	141
286.	Tobacco.	50 " "	27.42 " " "	121
290.	Oriskany.	50 " "	27.42 " " "	130
280.	Wheat.	55 " "	31.55 " " "	109
278.	River terrace.	55 " "	31.55 " " "	119
282.	Triassic.	55 " "	31.55 " " "	137
238.	Catskill.	55 " "	31.55 " " "	140
289.	Shales (Hamilton, &c.)	60 " "	36.14 " " "	123
288.	Helderberg limestone.	65 " "	41.22 " " "	100

It will be seen that the amount of space assigned to these different soil formations, has an important bearing on the relative rate with which water will move within the different soils. The coarser textured soils have less space and will contain less water than the clay soils. The subsoil of the truck land has only 45 per cent. of space, and will hold but 22.41 per cent. by weight of water, when this space is completely filled. The subsoil of the Helderberg limestone has 65 per cent. of space, and will hold 41.22 per cent. by weight of water, or nearly twice as much as the truck land. When the soils contained only 12 per cent. of water, a quantity of water would move through the truck land in 21 minutes, which would require 100 minutes to pass through the subsoil of the Helderberg limestone. When, however, these soils are taxed to their utmost, it will take 141 minutes for a quantity of water to pass through the truck land, which would go through the limestone subsoil in 100 minutes. As suggested in a previous section, this undoubtedly explains a matter of common observation and experience, that crops on these light lands are more injured by excessive wet seasons than crops on heavier soils.

These calculations of the relative rate with which water will move within these different subsoils, are based solely upon the skeleton structure. The influence of the organic matter is not considered, and the soil grains are assumed to have the same mean arrangement. These two factors, the amount of organic matter and the arrangement of the soil grains, are probably nearly alike under the normal conditions which prevail in these great soil formations; but if they have not relatively the same effect in the different soils, they will undoubtedly make the difference in the relation of these soils to the circulation of water, still wider than the values we have assigned. Each of these factors requires a distinct line of investigation, and this is necessary to the practical use and application of this work.

BULLETIN No. 2. A. S. 4.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF AGRICULTURAL SOILS.

SOIL MOISTURE.

A RECORD OF

THE AMOUNT OF WATER CONTAINED IN SOILS

DURING THE

MONTH OF JUNE, 1895.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1895.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF AGRICULTURAL SOILS,
Washington, D. C., September 16, 1895.

SIR: I have the honor to transmit herewith data showing the amount of moisture in the soils of a number of localities in the United States during the month of June, together with brief notes as to the character of the season and the crop conditions.

Very few reliable deductions can be made from observations extending over a single season, especially as the methods and object of the work were new to most of our observers. The information is therefore presented in a graphic way with but little criticism or comment.

Respectfully,

MILTON WHITNEY,
Chief of Division.

HON. J. STERLING MORTON,
Secretary of Agriculture.

CONTENTS.

THE WATER CONTENT OF SOILS DURING THE MONTH OF JUNE.

SUMMARY OF CONDITIONS DURING THE MONTH OF MAY.

The object of this work and the method used in keeping a record of the amount of moisture in soils has been briefly referred to in Bulletin No. 1 of this Division, which also contained statements showing the actual moisture conditions of the soils during the month of May. The conditions during that month may be briefly summarized as follows:

In the Eastern States the observers in the truck, tobacco, and grass regions reported generally very favorable soil conditions for the growing crops. In Kansas and Nebraska, on the other hand, the season was reported as extremely dry, little or no rain having fallen at most of the localities during the month, and but little for several months previous. The records showed that under these extremely dry conditions in many of the soils cultivation had maintained considerably more moisture in the first 12 inches than was found under the natural prairie sod. The grass had been an enormous drain upon the soil moisture, and had reduced the amount to about one-half of that contained in the cultivated land upon which no crop was allowed to grow. The amount of moisture in the fields under ordinary cultivation was still several per cent below the water content of the irrigated fields. In other localities, notably at Wellington, Stafford, and Mankato, Kans., cultivation appeared to have very little influence upon the amount of water in the soil during this dry season. It must be remembered that cultivation in itself does not make a soil more moist, but simply prevents the soil from drying out by retarding the excessive evaporation of the water from the surface. If, therefore, the soil is allowed to become dry, it is not to be expected that subsequent cultivation will make the soil materially wetter.

For the same reason the subsoiled plats from which the samples were taken showed little or no increase, and in many cases decidedly less water than the amount in the soil under ordinary cultivation. It was explained at the time that with one exception the subsoiling had been done in a very dry season and immediately before the observations were begun, so it could not be expected that these fields would show a larger water content. At one station in Nebraska subsoiling had been done some time before the observations were commenced and there had been subsequent rains; the amount of moisture in the subsoiled field was considerably more than in that under ordinary cultivation.

THE CONDITIONS DURING THE MONTH OF JUNE.

The conditions prevailing during the month of June are the reverse of those which occurred during the previous month. In the Eastern States the observers in the truck, tobacco, and grass regions reported the conditions rather too dry for the respective crops, at least during the middle and latter part of the month; the observers in Kansas and Nebraska, on the contrary, reported exceedingly favorable conditions of moisture. The rainfall was abundant and well distributed in showers occurring at intervals of a week or ten days. The observer at Garden City, Kans., reports that the season was so extremely favorable that no irrigation was needed during the month. At several of the other stations irrigation was not needed, except for a dry period beginning about the 20th and lasting for eight or nine days. Throughout the month, most of the observers reported crops in a very flourishing condition, with a good prospect for a fine corn crop. Some of the wheat also, which it was feared would be a total failure, took a fresh start under these favorable conditions and matured a fair crop in many localities, ripening a month later than usual. Many of the spring-planted crops were not planted under dry farming until after the rain of May 30 to June 2.

THE REPORTS FOR THE MONTH OF JUNE.

The data from Toano, Va., are from a typical truck land. Similar records from Maryland during this month show about the same conditions, and a normal water content of these truck soils appears to be between 5 and 10 per cent, the latter being rather too moist and the former rather too dry for the best development of the truck crops.

The data from the three types of tobacco land, including the bright tobacco, the dark shipping tobacco, and the white burley tobacco, appear to show characteristic conditions necessary for the proper development of these three classes of tobacco.

The moisture conditions most favorable to the bright tobacco appear to range from 6 to 8 per cent, 10 per cent making the soil rather too wet, while with only 5 per cent of moisture the soil is rather too dry. The dark shipping tobacco land has maintained on an average about 15 per cent of water, ranging from about 13 to 17 per cent. These conditions were reported as generally favorable to the crop. The soil adapted to the white burley tobacco maintained on an average about 20 per cent, and varied only from 19 to 21 per cent throughout the month. The conditions here also were reported as generally favorable to this crop. These marked differences in the amount of water contained in these three types of land appear to be very characteristic and to give the different soils their peculiar value for these crops. The bright tobacco soil can not maintain, under the conditions which prevail, as much water as the dark tobacco soil, but if the amount was materially larger than that shown by the records for this month, the crop would have partaken of the nature of the dark tobacco plants.

The records from Lexington, Ky., show that the grass in the sod land was an enormous drain upon the moisture. The supply of water was reduced to one-half that contained in the adjoining plat from which the sod had been removed, but which had been left without subsequent cultivation. The records further show the minimum or danger point at which pastures suffer in this land. On June 9, with 12 per cent of moisture in the soil of the sod land, the conditions were reported as very dry and rain as badly needed. After this the water content fell to 10 per cent by the 14th, which was several per cent less than the amount the crop required.

The conditions at Greendale, Ky., were very similar to those at Lexington, except that there were a number of local showers. Here again it is apparent that the grass was a very great drain upon the soil moisture, reducing the amount to 11 per cent, which indicates a very severe drought for that locality.

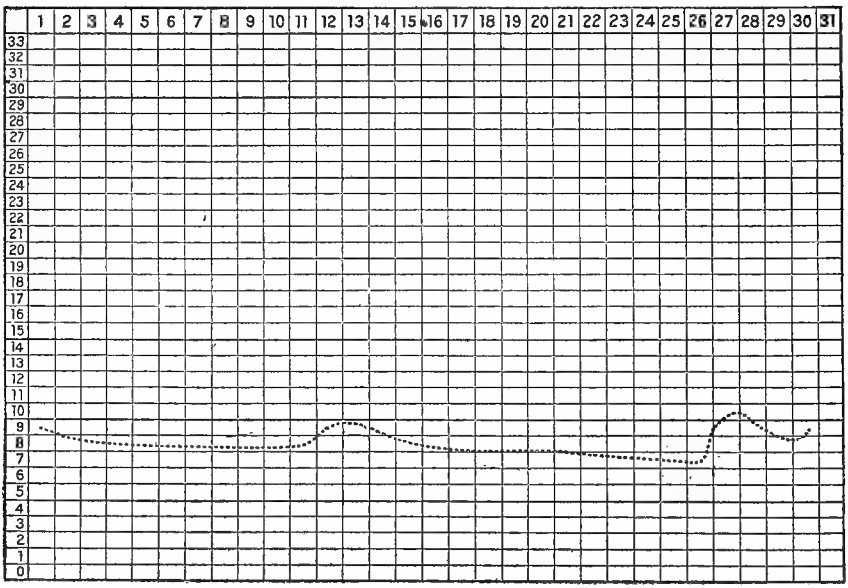
The records showing the conditions in the West are all commented upon directly under the diagrams. As a rule, during this favorable season the fields under ordinary cultivation and those which had been subsoiled and subsequently cultivated do not show very different moisture conditions. In some places the effect of cultivation is not apparent upon the moisture content of soils. For reasons which have already been given it is not to be expected that cultivation would show a very marked effect upon the amount of moisture in the soil either in a very dry season or in a very favorable season with frequent rains. The time when it would have its maximum effect would be after a wet season and when a dry period was coming on. The moisture content at this time should fall much more gradually in the cultivated than in the uncultivated land. This is shown to a slight extent in some of the records, but not to such an extent as would seem likely to occur under the most intelligent cultivation of the soil. The small amount of data which has been collected is not sufficient, however, to warrant a close and final judgment in this matter.

WHAT THE DIAGRAMS MEAN.

In the illustrations the vertical columns mark the days of the month, as indicated by the figures at the top of the diagram. The horizontal lines running across the diagram represent the percentage of moisture in the soil, as indicated in the column of figures on the left hand side of the illustration, extending from 0 to 33 per cent. As a guide to the eye, the lines representing every 5 per cent of moisture are made heavier.

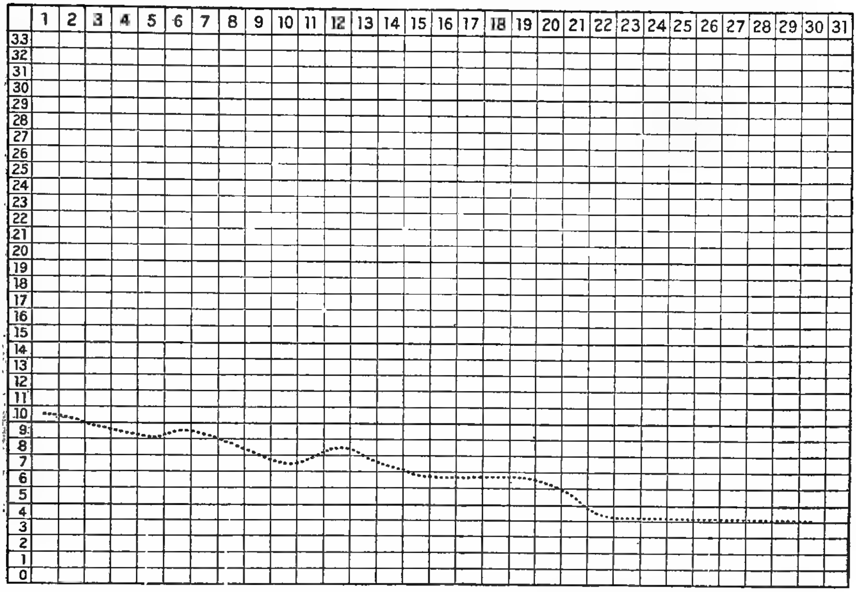
The records for each day of the month are put upon the form in their appropriate places. Thus, if on the 1st day of the month there is 8 per cent of moisture in the soil, a mark is placed in the column representing that day at a height corresponding to the figure 8 on the left-hand side of the page. If on the next day there is 12 per cent of moisture in the soil, a mark is made in the next column at a height corresponding with the figure 12, and so on for each day of the month. When these marks have all been placed, a permanent line is drawn through each of them, giving a more or less curved line according to the daily differences in the water contained in the soil. The marks are then rubbed out, and the curved line shows the monthly record. Where it is stated that there is 10 per cent of moisture in the soil, it means that on that date 10 per cent, or one-tenth of the weight of the soil in its natural position in the field to a depth of one foot from the surface, is water. When 20 per cent of water is present, it means that 20 per cent, or one-fifth of the weight of the soil as it lies in the field, is water. No crops were allowed to grow on any of the plats except two in sod land and four in prairie sod.

TOANO, VA.



Early tru

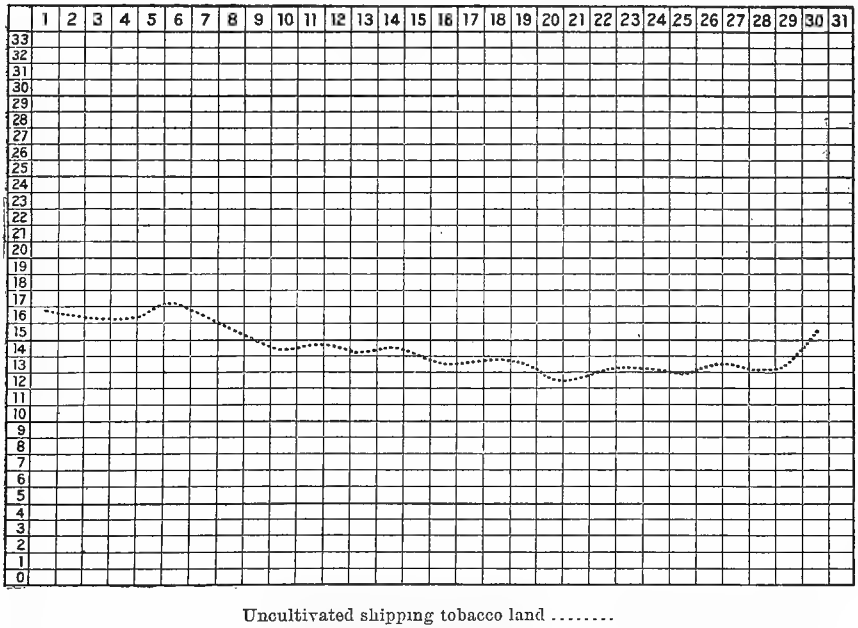
OXFORD, N. C.



Uncultivated bright tobacco land ....

Early part of month soil rather wet for growing crop; favorable for planting. Latter part of month soil rather too dry and rain needed.

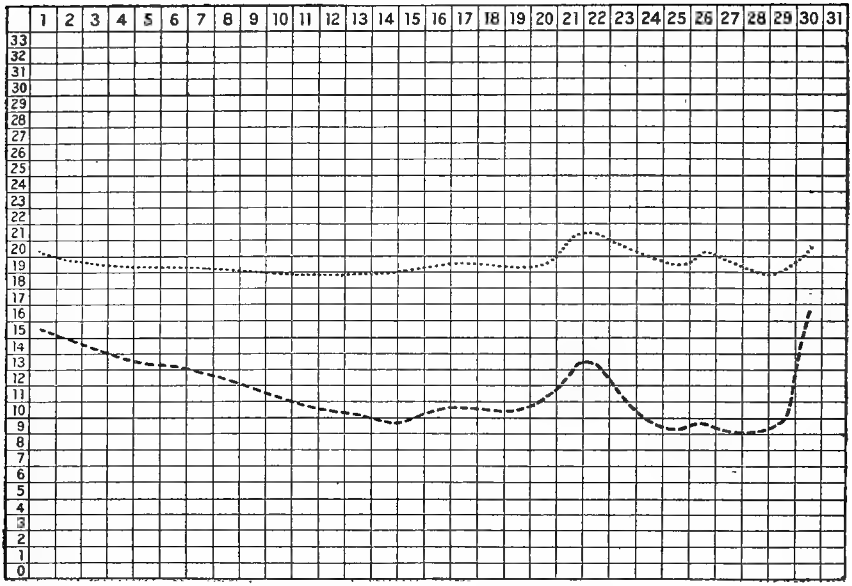
NEWSTEAD, KY.



Uncultivated shipping tobacco land ....

Up to middle of month soil condition reported as favorable for tobacco. Latter part of month reported rather dry. On June 10 crop reported as beginning to grow.

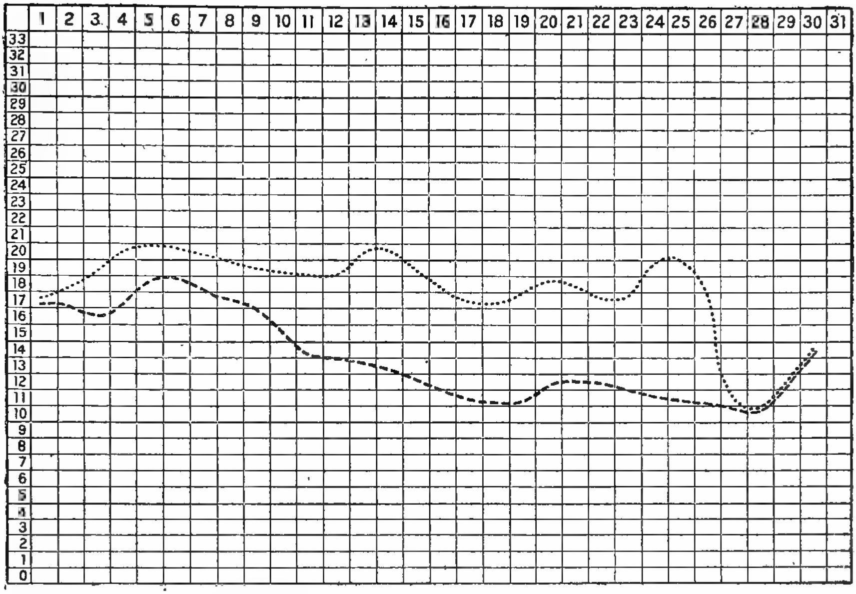
LEXINGTON, KY.



Uncultivated .... Blue-grass sod ▬▬▬▬

The soil was reported as too dry throughout the month, except for a slight shower, which made the conditions of the surface favorable, on June 4 to 6, and rain on the 20th, the effects of which were not apparent after June 22. On the 30th there was a heavy rain which made the soil too wet for a time. During the latter part of the month of May when the season was very favorable there was very little difference in the water content of the uncultivated and of the sod land. It can be seen from these curves that during the month of June the grass was an enormous drain upon the soil moisture. It diminished the amount of water to one-half of that contained in the uncultivated, reducing the amount from about 20 per cent to about 10 per cent. When the soil under the grass sod to a depth of 1 foot contained as little as 10 or 12 per cent of moisture, it was insufficient for this kind of vegetation. On June 27 the observer reported that the pasture was about dried up. The following notes were supplied by the observer: June 5, rain in the early morning, clear in the afternoon. Good season for tobacco planting. On the uncultivated soil, owing to the previous dry condition of the surface, the rain has been rapidly absorbed, the ground is drying out fast. June 9, hot and dry, rain badly needed. June 10, hot and dry, with dry winds. Grass burning up, crops need rain. From this time until June 15 hot, dry winds were reported. On June 15 there was a light local rain about noon which was rapidly absorbed. June 17 the surface seemed drier than before the rain of the 15th. On June 19 wheat harvesting began. On June 19 there was a light rain during the night and early morning followed by a cloudy day. June 25, dry winds. When sample was taken on June 26 the ground was slightly damp on the surface from showers in the afternoon. On June 28 the season was referred to as a severe drought, the ground being sc hard at that time that it was difficult to drive the sampling tubes. On June 30 there was a heavy rain in the afternoon and water was standing on the surface when the sample was taken.

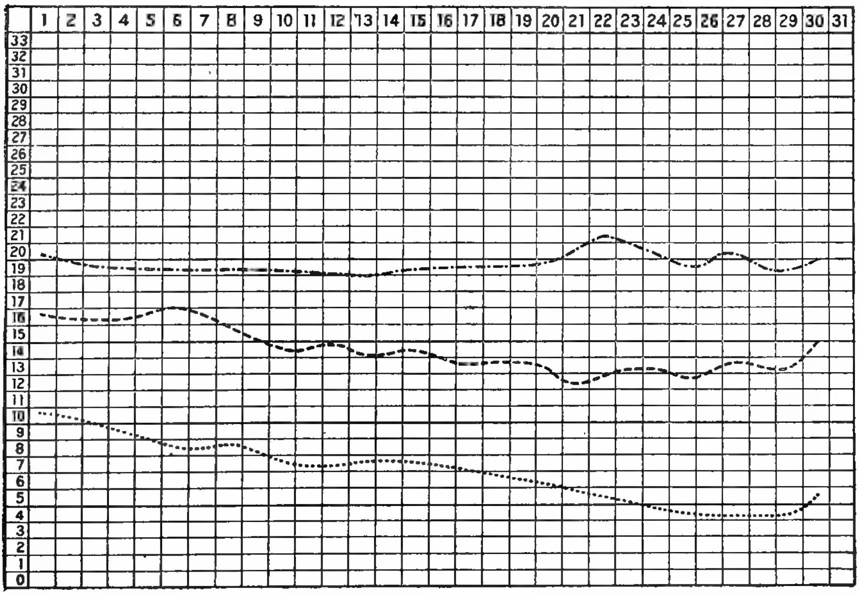
GREENDALE, KY.



Uncultivated .... Blue-grass sod ▬▬▬▬

Conditions were quite similar to those in Lexington, except that there were a number of local showers, which did the crops little good. Up to the middle of the month the crops were reported as fairly good. From the 17th to the last day of the month a severe drought was in progress and crops were reported as drying up.

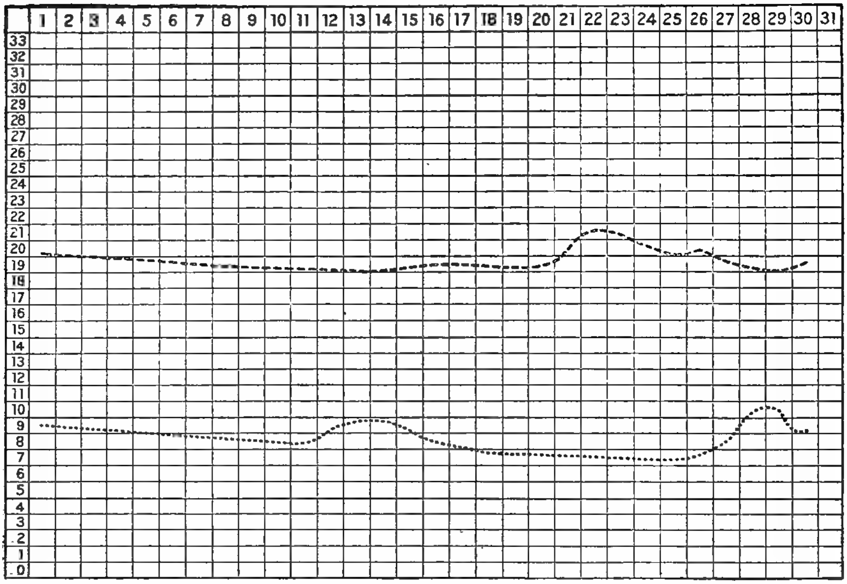
TYPES OF TOBACCO LAND.



Bright tobacco .... Shipping tobacco ▬▬▬▬ White burley tobacco ▬·▬·▬·

These curves show characteristic differences in the soil conditions adapted to the three classes of tobacco. The first part of the month was reported as generally favorable in all three localities, while the latter part of the month was rather too dry, and crops suffered from lack of sufficient moisture. This comparison indicates marked differences in the conditions adapted to these classes of tobacco.

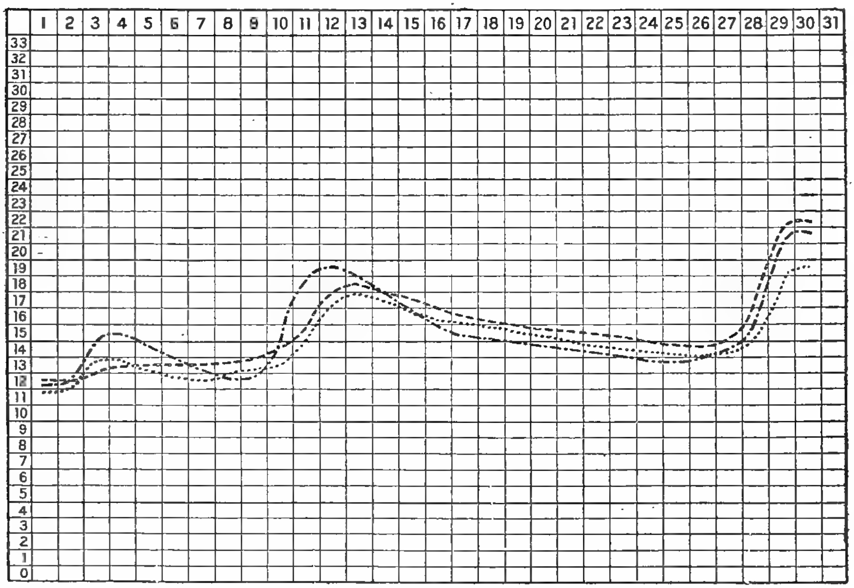
TYPES OF GRASS AND TRUCK LAND.



Early truck........ Grass land▬▬▬▬

These curves show the conditions in two extreme types of agricultural soils—truck and grass. If the curve here representing the conditions of moisture in the grass land represents the necessary conditions for that crop, it can readily be seen that the moisture conditions in the truck lands are entirely inadequate for grass. By referring to the chart showing the conditions at Lexington, Ky., it will be seen that when the soil under the grass sod contained even more moisture than is contained in the uncultivated truck land that the supply was inadequate for this crop and the pastures were drying up.

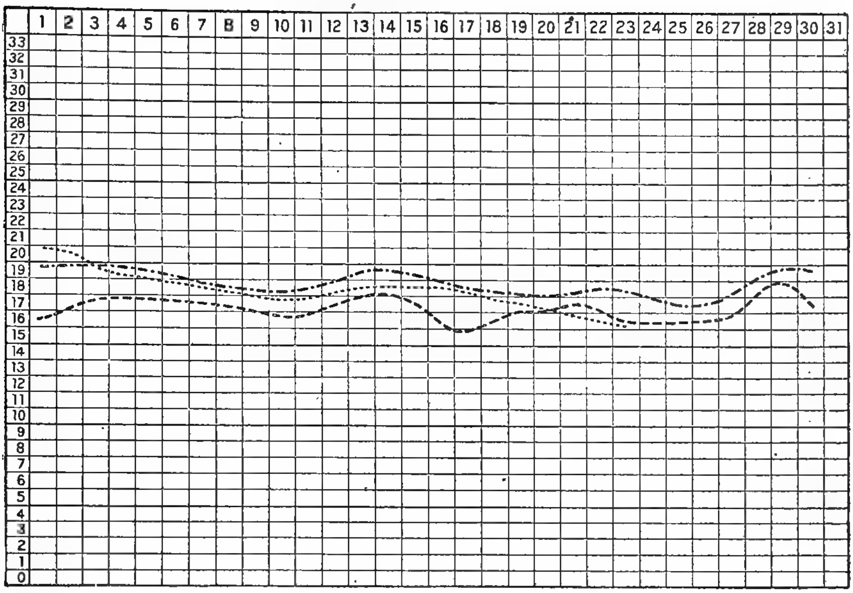
WELLINGTON, KANS.



Uncultivated .... Cultivated ▬▬▬▬ Subsoiled ▬·▬·▬

The soil conditions were generally favorable throughout the month. The dry season prevailing during the month of May was not broken until June 3. There were three rainfalls during the month of June, which kept the soil in good condition. The soil was reported as rather too dry for crops on the 1st, 8th, and 25th of the month and for a d[illegible] soiling nor ordinary cultivation appears to have l[illegible]

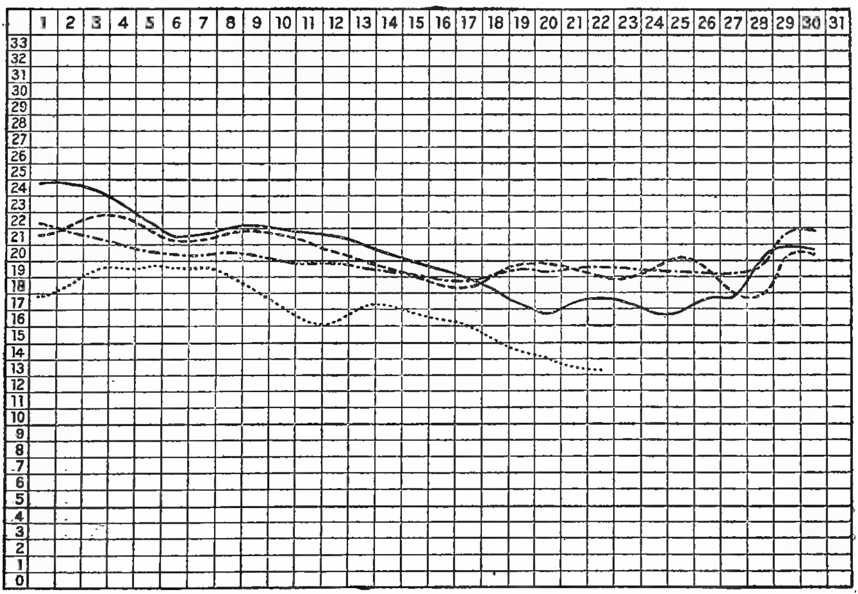
PHILLIPSBURG, KANS.



Uncultivated .... Cultivated ▬▬▬ Subsoiled ▬·▬·▬

The soil conditions were reported favorable throughout the month; the heavy rain of May 30 put the ground in good condition after the long drought which had prevailed, and frequent rains throughout the month of June kept the soil in a favorable condition for the crops. The observer writes on June 15 that wheat was almost a total failure; potatoes, corn, and alfalfa were in good condition. Everything at that time growing nicely. No marked effect of cultivation or subsoiling is apparent from these records.

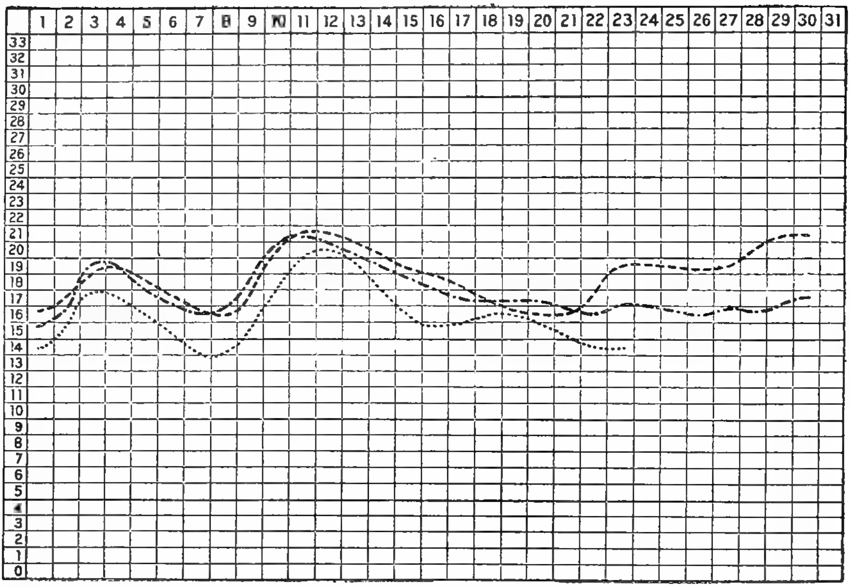
SCOTT, KANS.



Prairie sod .... Cultivated ▬▬▬ Subsoiled ▬·▬·▬ Irrigated ▬▬▬▬

The soil conditions were generally favorable throughout the month, except on June 3 and 4, when the surface was rather too wet for crops. On account of the drought prevailing in May, crops were plant

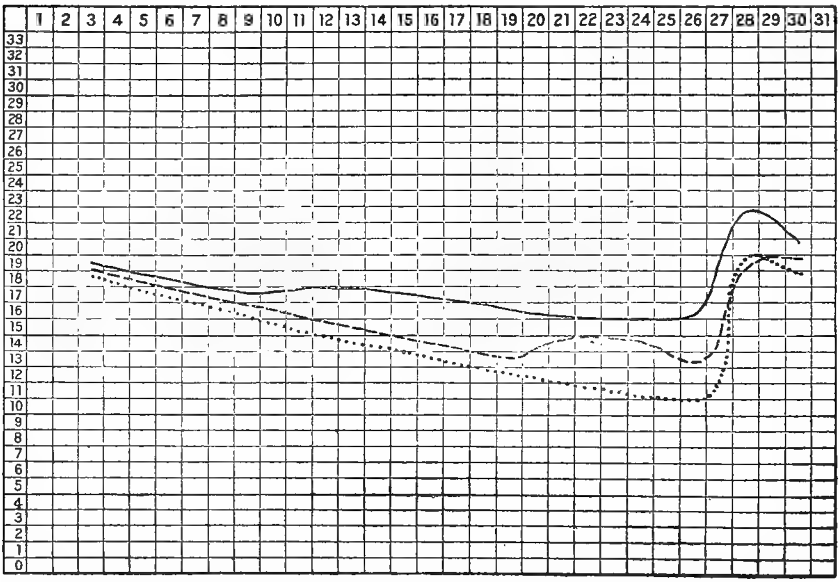
HAVEN, KANS.



Uncultivated .... Cultivated ▬ ▬ ▬ Subsoiled ▬ - ▬ -

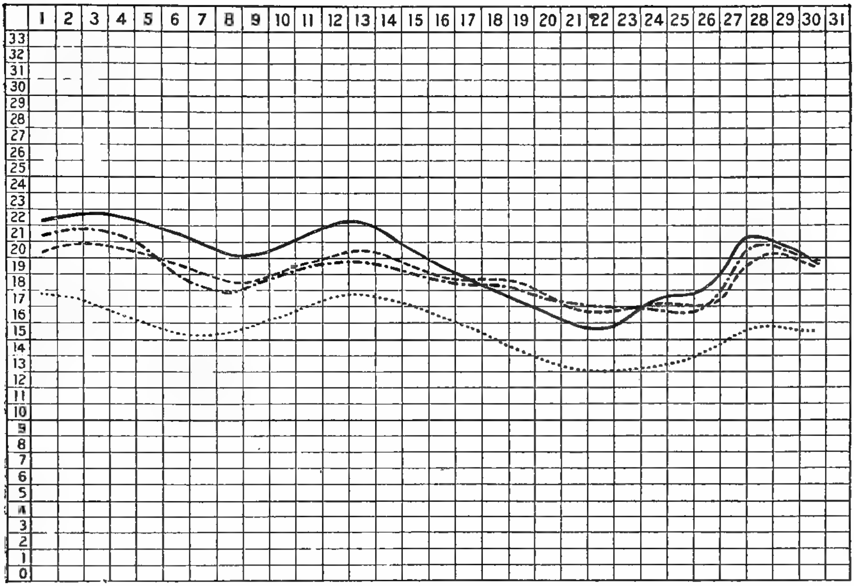
The soil conditions were reported as favorable throughout the month, except on June 3 and June 10 to 14, when they were reported as rather too wet. The moisture curves for the latter part of May show rather more moisture in the field under ordinary cultivation than in the subsoiled field. The records for June show very little difference between these two forms of cultivation. Nevertheless the observer wrote on June 15 that the crop in the adjoining subsoiled field was in much better condition than on the field under ordinary cultivation.

GARDEN CITY, KANS.



Prairie sod .... Cultivated ▬ ▬ ▬ Irrigated ———

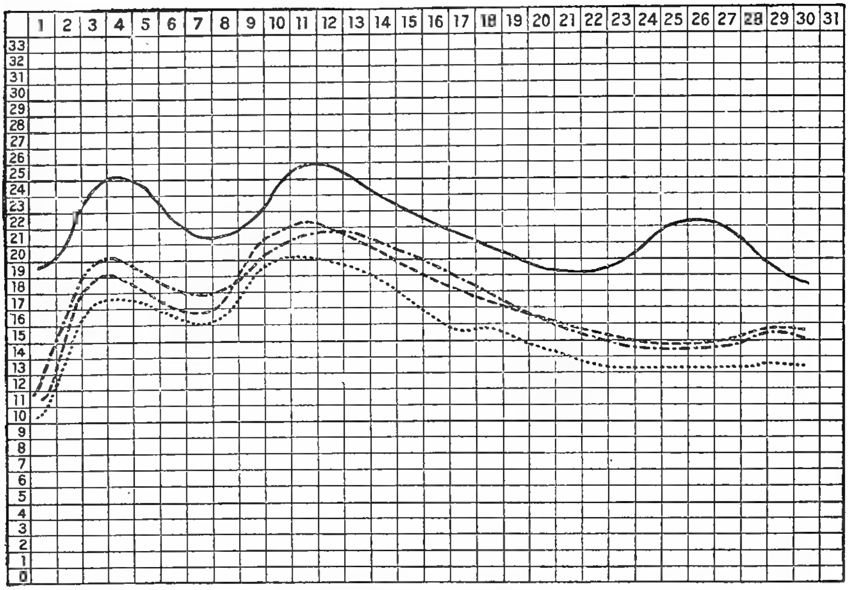
COLBY, KANS.



Prairie sod .... Cultivated ▬ ▬ ▬ Subsoiled ▬ ▪ ▬ ▪ Irrigated ▬▬▬

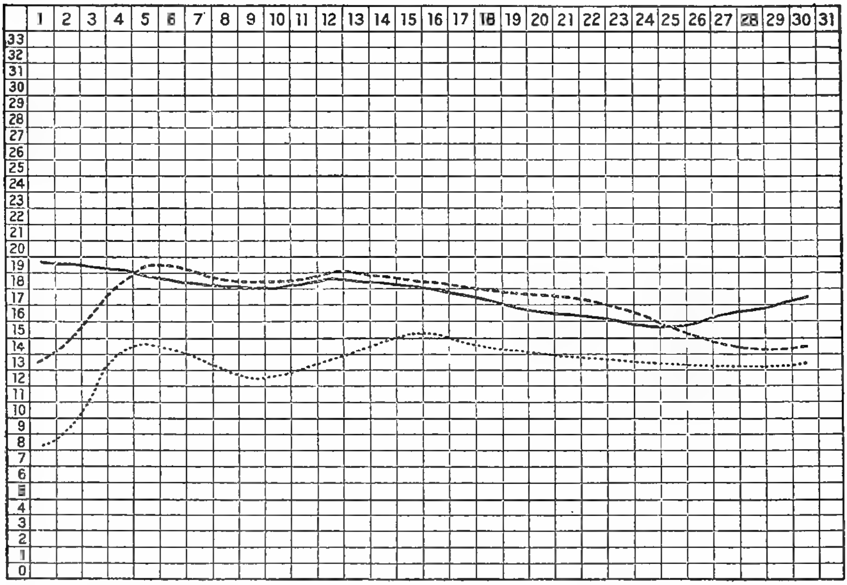
The conditions were generally so favorable through the month that it was not necessary to irrigate the crops. Very little difference is seen in the moisture content in the plots under ordinary cultivation and the subsoiled land. They contained, however, from 2 to 4 per cent more moisture than the prairie sod. The following conditions were reported by the observer: About an inch of rain fell on June 9 to 12, and on June 14 fine growing weather was reported. On June 22 wheat and barley were reported headed out, but in need of rain. On June 24 hot winds prevailed, and the thermometer recorded 100° in the shade; small grains reported as suffering. Nearly an inch of rain fell June 27 and 28.

STAFFORD, KANS.



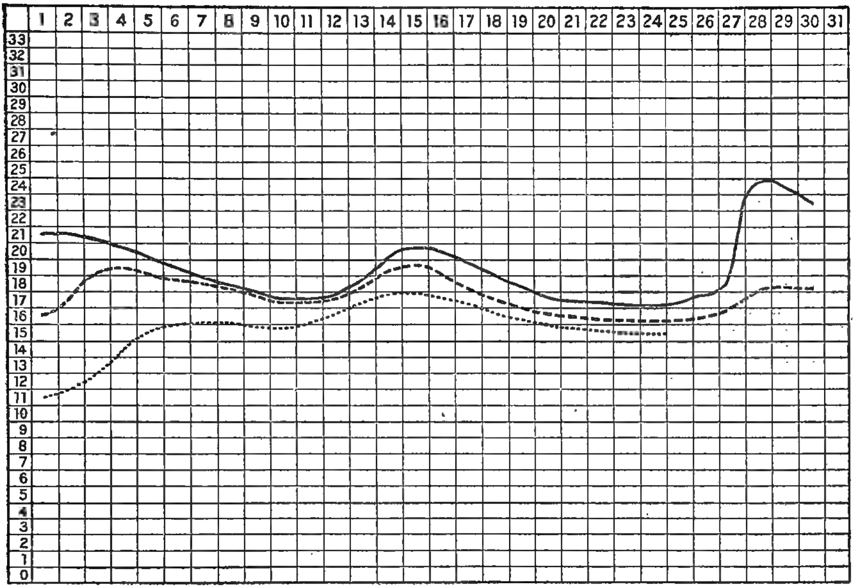
The drought prevailing during the month of May ended with a copious rain on June 2. On June 1 the observer reported the crops had not been planted for dry farming, as the soil had been too dry. On irrigated land the soil was in good condition and crops were in bloom. The conditions continued generally favorable throughout the month. Very little difference was seen in the water content under subsoiled and ordinary cultivation.

ELLINWOOD, KANS.



The dry condition of the soil during the month of May was hardly affected by the rain of May 30, and on June 1 the soils were reported too dry. This was followed by copious rain, and conditions were reported generally favorable until June 23, when the temperature was exceedingly high and the crops were reported as suffering for water.

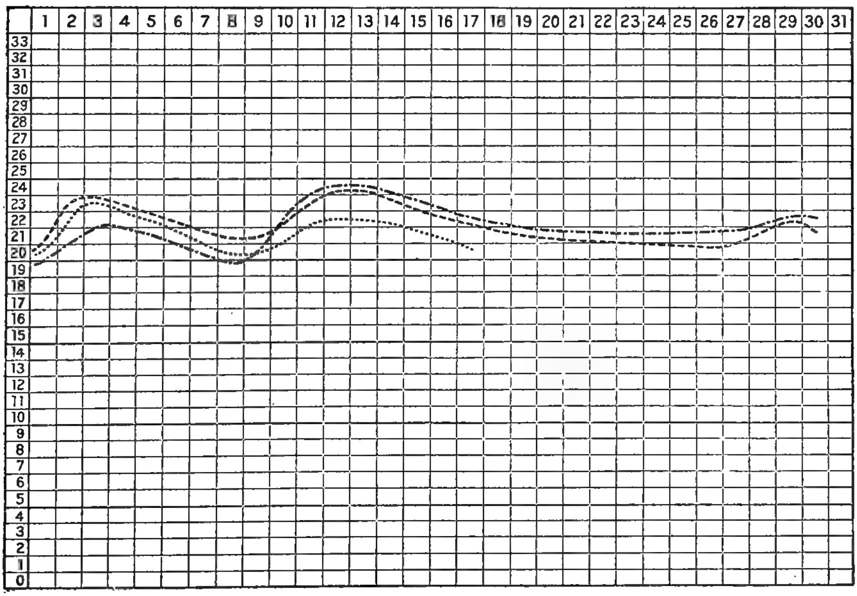
FOWLER, KANS.



Prairie sod .... Cultivated ▬▬▬ Irrigated ▬▬▬

After the rain of May 30 and June 2 the soil conditions were very favorable except from June 8 to 11 and June 24 to 26, when it was reported as rather dry for crops.

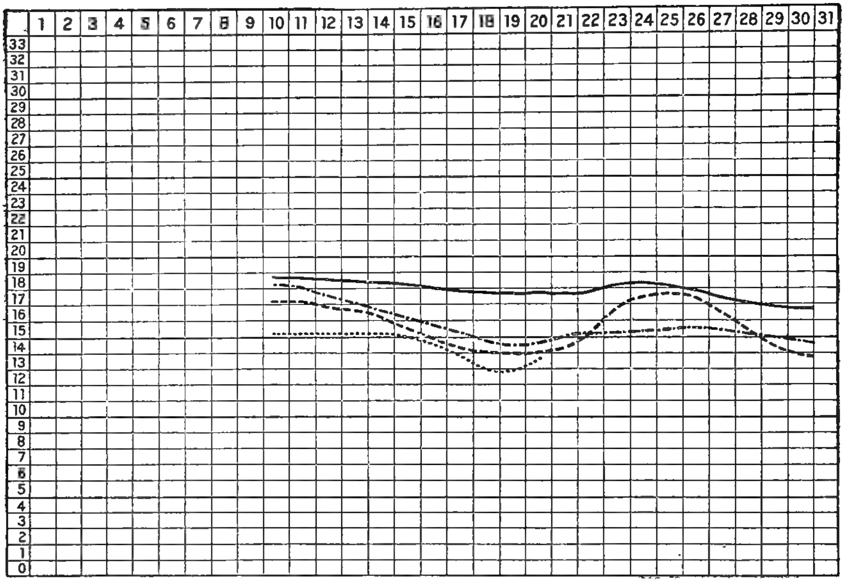
MANKATO, KANS.



Uncultivated .... Cultivated ▬▬▬ Subsoiled ▬▬▬

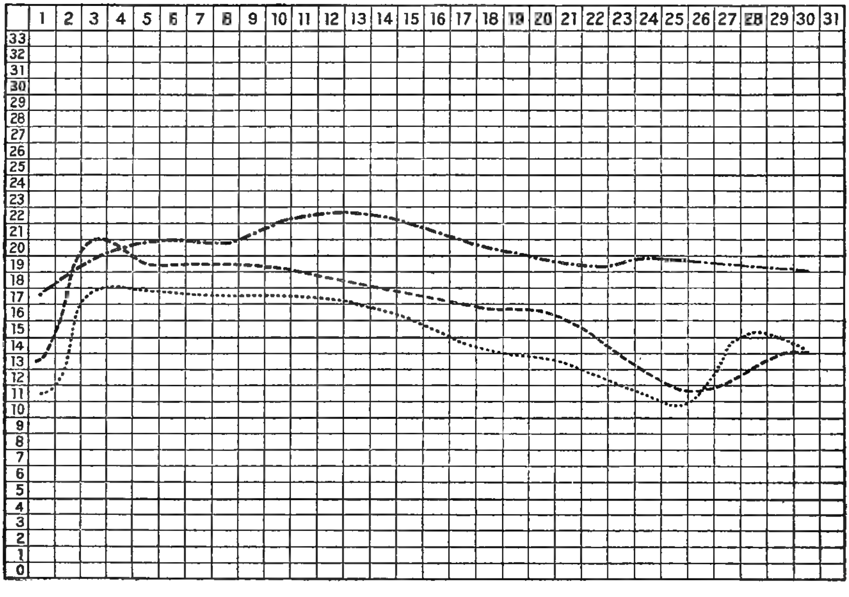
The observer at this point reports a hot moist month, with thrifty crops. June 21 and 22 the soil was reported as rather dry for oats and wheat, but favorable for corn. The average moisture content of this soil is much above that of the other stations in Kansas.

BIG SPRINGS, NEBR.



Uncultivated .... Cultivated ▬ ▬ ▬ Subsoiled ▬ · ▬ · ▬ Irrigated ▬▬▬

GENEVA, NEBR.



Prairie sod .... Cultivated ▬ ▬ ▬ Subsoiled ▬ · ▬ · ▬

This station (as noted in the May bulletin) is the only one at which the subsoiling was done a sufficient time prior to the taking of samples to insure a moistening of the soil as deep as stirred. Here the subsoiled plot shows a remarkably even curve—from 2 to 8 per cent higher than that under ordinary cultivation.

BULLETIN No. 3. A. S. 5.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF AGRICULTURAL SOILS.

SOIL MOISTURE.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF AGRICULTURAL SOILS,
Washington, D. C., November 11, 1895.

SIR: I have the honor to transmit herewith data showing the amount of moisture in the soils of a number of localities in the United States during the month of July, with brief notes as to the character of the season and the crop condition.

The investigations of the texture and moisture conditions of some of the important soils which have been studied this year have been carried so far that some generalizations seem permissible. Accordingly the texture of the soils adapted to truck, grass, and three different types of tobacco is described in this bulletin as the principal cause of the marked difference in the amount of moisture found in the soils. It is further stated that the well-known difference in the agricultural value of these several kinds of soils and their adaptation to certain crops is largely due to the relative amount of water which these soils maintain for crops.

The records for August do not differ materially from those which have been reported in this and in previous bulletins. While the moisture differs in the same soil from day to day and from week to week, the difference is proportionally the same on all the soils, showing that throughout the season crops growing on some soils have two or three times as much water at their disposal as on others under essentially the same climatic conditions. This point having been established it will not be necessary to publish more of these preliminary records at present.

Very respectfully,

MILTON WHITNEY,
Chief of Division.

Hon. J. STERLING MORTON,
Secretary of Agriculture.

CONTENTS.

THE WATER CONTENT OF SOILS DURING THE MONTH OF JULY.

SUMMARY OF CONDITIONS DURING THE MONTHS OF MAY AND JUNE.

The soil conditions during the months of May and June presented some curious phenomena. During the latter half of May, over which the records were reported, the conditions in the soils of the arid region were reported as extremely dry. At the East, in the truck, tobacco, and grass lands of the Atlantic Coast States, the conditions were reported as extremely favorable for these crops, inclined even to be rather wet over portions of the time. In June the situation was just reversed. On the last day of May and the first two days of June rain fell throughout Kansas and Nebraska, followed by frequent showers throughout the month, so that the conditions throughout June were reported as generally very favorable for crops produced in those localities. The fall-planted crops had been greatly delayed on account of the drought prevailing throughout the spring, and on account of the dry-soil conditions the spring-planted crops could not be put out until later than usual, except on irrigated fields. The first of June, therefore, marked the beginning of spring and of farming operations for the States of Kansas and Nebraska. In the truck, tobacco, and grass lands of the Eastern States the soil conditions during June were very dry, and great injury was reported in consequence from many localities. The drought was so severe that the pastures dried up even in the finest type of grass land. These unfavorable conditions were graphically shown in the charts accompanying Bulletin No. 2 of this division.

CONDITIONS DURING THE MONTH OF JULY.

The soil conditions prevailing during the month of July were generally favorable throughout all the localities from which records were obtained. In western Kansas and Nebraska there were frequent and abundant showers, so that at most of the localities at which observations were taken no irrigation was needed, and the crops were reported as making a very luxuriant growth. In the Eastern States the conditions were generally reported favorable from the localities at which the records were kept.

MOISTURE CONDITIONS IN TRUCK AND GRASS LANDS.

In Bulletin No. 2 reference was made to the fact that the early truck of the Atlantic Seaboard is grown upon a very characteristic type of soil. These truck soils are light and sandy, and from the old agricultural standpoint are poor and unproductive for the staple farm crops. The pasture grasses, on the other hand, for their best development require the strongest type of agricultural land. Two localities were selected for the comparison of the conditions prevailing in these two markedly different types of soil. Toano, Va., was selected for the truck, and Lexington, Ky., for the grass land. There have been sufficient data collected now to warrant some generalizations, and the following data is given as an explanation of the cause of the marked difference in agricultural value of these two soils and of their peculiar adaptation to these different kinds of crops and agricultural interests.

The accompanying table gives the mechanical analyses of a sample of subsoil of the truck land at Toano, Va., and of the grass land at Lexington, Ky.

Texture of land adapted to extreme types of agricultural crops—truck and grass.

No.	Diameter of soil grains.	Conventional names.	371. Toano, Va., truck land, 6–24 inches.	287. Lexington, Ky., grass land, 7–24 inches.
	Millimeters.		*Per cent.*	*Per cent.*
1	2–1	Fine gravel	0.06	1.76
2	1–0.5	Coarse sand	0.46	1.63
3	0.5–0.25	Medium sand	7.08	1.24
4	0.25–0.1	Fine sand	48.43	0.58
5	0.1–0.05	Very fine sand	26.20	1.59
6	0.05–0.01	Silt	8.52	46.36
7	0.01–0.005	Fine silt	3.20	9.56
8	0.005–0.0001	Clay	4.55	30.20
	Total mineral matter		98.50	92.92
9	Loss at 110° C.		0.15	4.29
10	Loss on ignition		1.10	5.32
	Total		99.75	102.53

It will be seen that the soils differ very markedly in their texture. The truck soils of the Atlantic Coast contain from 1 to 10 per cent of clay. As a rule, the less clay they contain the earlier the crops mature, which is the most important element in truck farming. A soil containing between 4 and 5 per cent of clay, as shown in this sample, is an average truck soil adapted to any of the usual truck crops. The truck soils, as a rule, consist of from 70 to 85 per cent of the different grades of sand. The finest type of grass land in the Eastern States, on the other hand, contains a very much larger percentage of clay. It contains not more than 5 or 10 per cent of the various grades of sand and from 28 to 50 per cent of clay.

On account of this marked difference in the texture of these soils, they maintain, even with the same rainfall, very different conditions of moisture, and this adapts them to different classes of crops.

The trucking interest depends upon the early maturity of vegetables and small fruits, so that they can be put upon the market before there is competition from other soils of the State. It is carried on under a very intense system of cultivation. The value of the truck crops of Maryland is about equal to the value of the wheat crop and nearly equal in value to the corn crop, but the truck farming is confined to a narrow belt of land along the coast and Chesapeake Bay, and in the aggregate there is not more than one-tenth of the corn acreage devoted to this interest. This is without considering the market gardening around the larger cities and the production of fruits, which would very materially increase the relative importance of this class of agricultural crops without greatly extending the acreage.

These truck soils do not yield as much per acre nor is the quality of the crops produced as fine as on the heavier soils of the State, but vegetables can be forced to mature early and be placed upon the market during the winter and early spring months sometime before they can be matured upon the heavier soils.

The principal reason for this and the explanation of the peculiar adaptation of these soils to truck farming is to be found in the open, loose texture of the soils and the small, but uniform, supply of water they maintain for the crops.

The pasture grasses represent the other extreme of agricultural interests and require, as was stated, the richest and finest type of agricultural lands. A pasture grass rarely needs to mature seed. It needs a soil in which there is an abundant and uniform supply of moisture to promote a continuous and luxuriant vegetable growth, with little tendency to produce fruit. On our heaviest limestone soils all kinds of cultivated crops are inclined to make a luxuriant growth, to be slow in maturing, and to produce a relatively small yield of grain or fruit in proportion to the weight of dry matter produced. The agricultural value of these lands is largely dependent upon the close texture of the soil and the large and uniform supply of water they maintain for the crops.

When rain falls upon these two types of soil, it continues to soak through the soils until it reaches sea level, unless indeed it is used by plants or evaporated from the surface of the ground. The rate with which it moves downward through these soils is, however, very different on account of the variance in texture. In the light, sandy soil the spaces between the grains are relatively large, and the rain moves downward without much friction. In the heavy, clay soils, on the other hand, with less than 10 per cent of sand, the movement is extremely slow, as the water has to move down through an innumerable number of spaces between the fine grains of clay, and the friction or the resistance is very great. With the same rainfall, therefore, over each of these soils, on account of the greater friction and the slower movement in the clay soil that type of land will maintain two or three times as much water as is contained in the truck soil. The effect of this is very apparent in the yield, texture, and other qualities of the crop.

The following table shows the amount of moisture in these two types of soil for the months of June and July:

Per cent of moisture in soils adapted to truck and grass.

Date	June.		July.		Date.	June.		July.	
	Truck.	Grass.	Truck.	Grass.		Truck.	Grass.	Truck.	Grass.
1	9.5	20.2	10.3	21.1	18	7.8	19.3	9.8	18.1
2	9.4	20.1	10.4	21.3	19	7.8	19.2	9.1	18.0
3	9.3	20.0	9.7	20.7	20	7.7	19.3	8.2	18.1
4	9.2	19.9	9.0	20.1	21	7.7	20.5	7.6	18.8
5	9.0	19.8	8.2	19.7	22	7.6	21.5	7.0	20.0
6	8.9	19.7	7.9	19.7	23	7.5	21.4	6.2	21.4
7	8.8	19.6	8.2	20.0	24	7.4	20.7	6.2	22.4
8	8.7	19.4	8.7	20.2	25	7.4	20.1	7.5	23.1
9	8.6	19.3	9.3	20.6	26	7.7	20.3	9.1	23.1
10	8.5	19.2	9.4	20.8	27	8.5	19.7	8.9	22.8
11	8.4	19.2	9.6	20.9	28	10.3	19.3	8.5	22.3
12	9.2	19.2	9.3	20.7	29	10.5	19.1	8.0	21.8
13	9.8	19.1	9.1	20.3	30	9.1	19.6	7.2	21.2
14	9.8	19.1	9.0	19.8	31			6.5	20.7
15	9.2	19.3	9.6	19.2					
16	8.5	19.4	10.2	18.2	Mean	8.7	19.7	8.6	20.4
17	8.1	19.5	10.1	18.3					

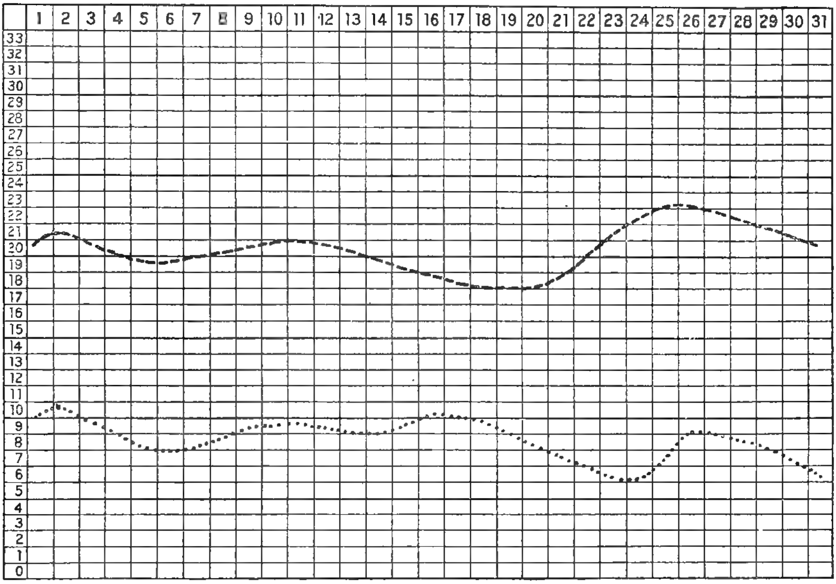
These figures are not those obtained from the daily samples, for the actual determinations vary considerably with the inequalities of the ground and from the errors arising from the methods of moisture determinations. The actual determinations are plotted on a chart, and the figures in the table are taken from the chart as representing more nearly the average daily conditions of the field.

The conditions in the truck soil were reported as generally favorable throughout the month of June. In the uncultivated grass land the conditions were quite uniform, as seen, but under the pasture sod the amount of water was reduced to about one-half of that on the bare, uncultivated land. The conditions were represented as generally favorable throughout the month of July for the respective crops of each locality. It will be seen that in the month of June there was, on the average, 8.7 per cent of moisture in the truck soil. The highest was 10.5 on the 29th, and the lowest 7.4 on the 24th and 25th. There was on the average 19.7 per cent of moisture during the same time in the grass land, and the conditions were reported as rather dry. The largest amount was 21.5 per cent, and the smallest amount was 19.1 per cent on June 13, 14, and 29. These records were both taken from bare, uncultivated soil, so that the conditions of the observations would be the same and the observations comparable. In July, when the conditions were reported as quite favorable in each locality for the respective crops, there was an average of 8.8 per cent of moisture in the truck soil, the extreme being 10.4 to 6.2 per cent. In the grass land there was an average of 20.4 per cent, with extremes of 23.1 to 18 per cent.

Observations taken at Mardela Springs, Md., representing the lighter truck soils of eastern Maryland, show an average water content for July of 6.5 per cent, with a range from 10.3 to 4.5 per cent. Observations taken elsewhere in the truck and grass areas confirm the facts here presented, and indicate that our typical truck soils maintain on an average from 5 to 10 per cent of moisture, while our strongest types of grass land maintain on an average from 18 to 22 per cent of water.

The accompanying chart shows graphically the difference in the amount of water contained in these two types of land during the month of July. The records for June when plotted show precisely the same

Per cent of moisture in truck and grass land in July.



Early truck land .... Grass land ▬ ▬ ▬

relative position of the curves. It is very evident that this difference in the water content, due to the difference in texture of the soils, is the principal reason for the peculiar agricultural value of these two markedly different types of land.

MOISTURE CONDITIONS IN DIFFERENT TYPES OF TOBACCO SOIL.

The accompanying table gives the mechanical analyses of three soils, each adapted to a different class of tobacco—the bright tobacco of North Carolina; the dark, heavy shipping tobacco of Kentucky; and the coarse, rank, white burley tobacco of Kentucky.

Texture of soils adapted to three types of tobacco.

No.	Diameter of soil grains.	Conventional names.	117. Oxford, N. C., bright tobacco, 12–16 inches.	1099. Newstead, Ky., shipping tobacco, 6–18 inches.	287. Lexington, Ky., burley tobacco, 7–24 inches.
	Millimeters.		*Per cent.*	*Per cent.*	*Per cent.*
1	2–1	Fine gravel	0.71	0.05	1.76
2	1–0.5	Coarse sand	1.12	0.18	1.63
3	0.5–0.25	Medium sand	7.37	0.11	1.24
4	0.25–0.1	Fine sand	27.90	0.34	0.58
5	0.1–0.05	Very fine sand	24.26	5.13	1.59
6	0.05–0.01	Silt	22.77	63.28	46.36
7	0.01–0.005	Fine silt	4.20	5.19	9.56
8	0.005–0.0001	Clay	8.30	20.55	30.20
	Total mineral matter		96.63	94.83	92.91
9	Loss at 110° C		2.07	2.10	4.29
10	Loss on ignition		0.15	3.06	5.32
	Total		98.85	99.99	102.52

It will be seen that the texture of these samples is very different. The samples represent very uniform soil areas, upon which these different classes of tobacco are grown. Samples of the bright-tobacco soils have been examined from a great many localities in Virginia, North and South Carolina, and East Tennessee, and their texture is remarkably uniform. They contain from 4 to 10 or 12 per cent of clay. As a rule, the less clay they contain the finer the texture and the brighter the color that can be given to the tobacco in curing. Such light soils, however, produce but a small yield per acre, and there is a limit of profitable production beyond which the finer quality does not compensate for the smaller yield.

The dark, heavy, shipping tobaccos of Kentucky are grown upon a soil of medium texture, containing on an average about 20 per cent of clay. The sample selected as representing this grade of land is from the barrens formation at Newstead, Ky., and contains considerably more silt than is usually found in these soils. The burley tobacco is grown upon the rich limestone soils, which can hardly be too rich and productive for this class of tobacco. These soils contain from 30 per cent of clay upward.

Per cent of moisture in soils adapted to three different types of tobacco.

Date.	June.			July.		
	Bright tobacco.	Shipping tobacco.	Burley tobacco.	Bright tobacco.	Shipping tobacco.	Burley tobacco.
1	10.6	16.7	20.2	11.3	16.6	21.1
2	10.4	16.5	20.1	11.7	17.5	21.3
3	10.0	16.3	20.0	11.2	16.8	20.7
4	9.5	16.4	19.9	10.7	15.5	20.1
5	9.0	16.7	19.8	10.0	15.1	19.7
6	8.5	17.0	19.7	9.1	15.2	19.7
7	8.5	16.6	19.6	8.3	16.0	20.0
8	8.6	15.9	19.4	7.6	17.3	20.2
9	8.2	15.2	19.3	7.0	17.9	20.6
10	7.7	14.6	19.2	6.3	17.5	20.8
11	7.3	14.6	19.2	5.9	17.1	20.9
12	7.3	14.8	19.2	5.5	16.8	20.7
13	7.5	14.2	19.1	5.3	16.2	20.3
14	7.6	14.2	19.1	5.1	15.7	19.8
15	7.5	14.5	19.3	4.9	15.3	19.2
16	7.3	14.0	19.4	4.8	14.9	18.8
17	7.1	13.6	19.5	4.6	14.4	18.3

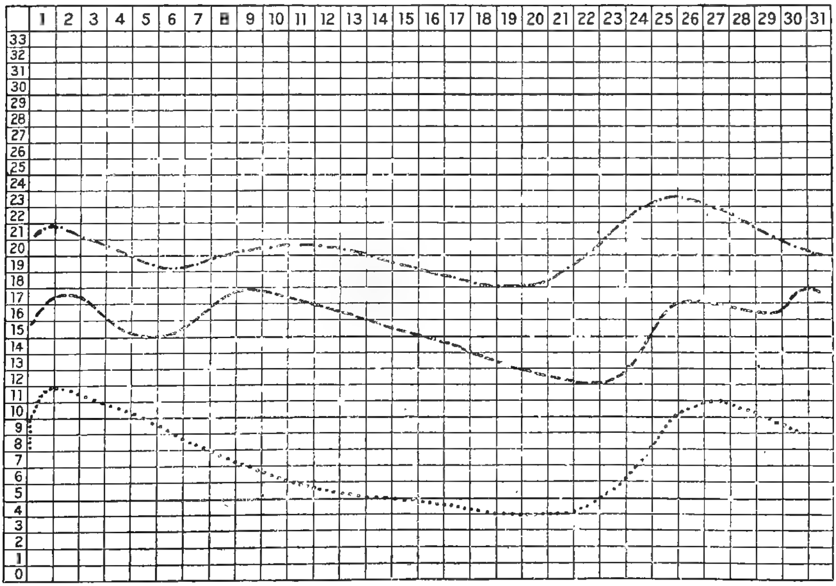
Per cent of moisture in soils adapted to three different types of tobacco—Continued.

Date.	June.			July.		
	Bright tobacco.	Shipping tobacco.	Burley tobacco.	Bright tobacco.	Shipping tobacco.	Burley tobacco.
18	6.8	13.7	19.3	4.2	13.7	18.1
19	6.5	13.7	19.2	4.0	13.2	18.0
20	6.2	13.1	19.3	4.0	12.8	18.1
21	5.8	12.4	20.5	4.0	12.3	18.8
22	5.5	12.7	21.5	4.5	12.1	20.0
23	5.2	13.2	21.4	5.5	12.3	21.4
24	4.8	13.2	20.7	7.0	13.6	22.4
25	4.5	12.8	20.1	9.5	16.4	23.1
26	4.3	13.0	20.3	10.6	17.1	23.1
27	4.2	13.7	19.7	11.0	16.9	22.8
28	4.2	13.3	19.3	10.5	16.7	22.3
29	4.3	13.3	19.1	10.0	16.4	21.8
30	5.5	14.8	19.6	9.1	17.5	21.2
31					17.5	20.7
Mean	7.0	14.5	19.7	7.4	15.6	20.5

The accompanying table gives the daily moisture content of these three types of tobacco soils for the months of June and July, the soil from Lexington, Ky., being used as a representative both of the grass and the white burley-tobacco land. In June the bright-tobacco soil contained on an average, to a depth of 12 inches, 7 per cent of moisture; the shipping-tobacco soil 14.8 per cent, and the burley-tobacco soil 19.7 per cent. In July the average moisture content of the three soils was about the same.

The data for July is shown graphically in the accompanying chart. The three curves have the same relative position as shown in the records for June, published in Bulletin No. 2 of this division.

Diagram showing the per cent of moisture in three types of tobacco land during month of July.



Bright tobacco ...... Shipping tobacco ▬▬▬▬ Burley tobacco ▬·▬·▬

The soils adapted to each of these classes of tobacco differ so much in their texture and in their general appearance that it is easy for anyone with a little experience in such matters to recognize and classify them from a casual inspection and from the general appearance of the soil.

The typical "bright tobacco" can not be produced upon a soil having the same texture and maintaining the same moisture conditions as the shipping-tobacco soil here represented. The leaf would be coarse in texture and would not take on a golden color in curing, which gives character to the bright tobacco. On the other hand, a dark shipping leaf can not be produced upon the bright-tobacco soils, although it is easy to darken the leaf and make it coarser by changing the soil conditions through the application of manures and fertilizers. The texture of the soil adapted to each of these three classes of tobacco is very uniform, but there is a characteristic distinction between the classes, and the amount of water maintained by the various soils is quite different. When this amount of water is materially changed, either by artificial means or by the character of the season, the character of the crop produced is also materially modified and changed. The conclusion seems fully justified that the peculiar agricultural value of each of these three types of soil and their adaptation to one or the other of these three types of tobacco are very largely dependent upon the texture of the soil and upon the water supply which it maintains, which determines the peculiar development of the plant and the texture and quality of the leaf.

REPORTS FOR THE MONTH OF JULY.

The character of the soil conditions and of the season are referred to under the charts for the respective localities. Data is given from two localities in the truck area, one each in Maryland and Virginia. The moisture condition adapted to this interest is when the soil contains from 5 to 10 per cent of water, calculated on the moist material. When the supply falls below 5 per cent, the crop suffers, as a rule, from lack of moisture. When the supply exceeds 10 per cent, the soils are rather too wet for cultivation and too moist for the best development of truck crops, except during the early stages of growth.

The bright-tobacco soils have nearly the same texture as the truck soils, and maintain about the same amount of moisture for the crops. This amount should not much exceed 10 per cent, except when the crop is actively growing, and should not fall below 5 per cent.

The observations taken in the soil at Poquonock are believed to represent the typical conditions of the soils of the Connecticut Valley, which produce the fine-textured, light-colored cigar wrappers adapted to our home markets, of the same general type as the Sumatra tobacco. It will be seen that the moisture conditions in these tobacco soils are quite similar to the conditions in the bright-tobacco lands of the South, and to the truck soils of the Atlantic Seaboard. Indeed, these tobacco soils of the Connecticut Valley are typical truck soils, and are used extensively for this purpose. It was shown last season that in the tobacco soils of Pennsylvania, where the Cuban type of tobacco is produced, which is larger, heavier, and coarser in texture than the Sumatra, there were two or three times as much moisture as in the light-tobacco soils of the Connecticut Valley.

The records from Greendale and Lexington, Ky., show, as did the June records, the great drain that pasture grasses are upon the moisture content of the soil.

The subsoiled plots, which have been studied during this season in Kansas, give hardly a fair idea of the effect of subsoiling, for the work was done when the land was extremely dry, and in some cases at least it was poorly done, on account of the dryness of the soil. It was done immediately before the observations were commenced, and several weeks before a soaking rain occurred to wet the soil. Since then the season in Kansas up to the last of July has been exceedingly favorable owing to the frequent showers. Under these conditions the subsoiling could hardly have been expected to show any material changes in soil conditions.

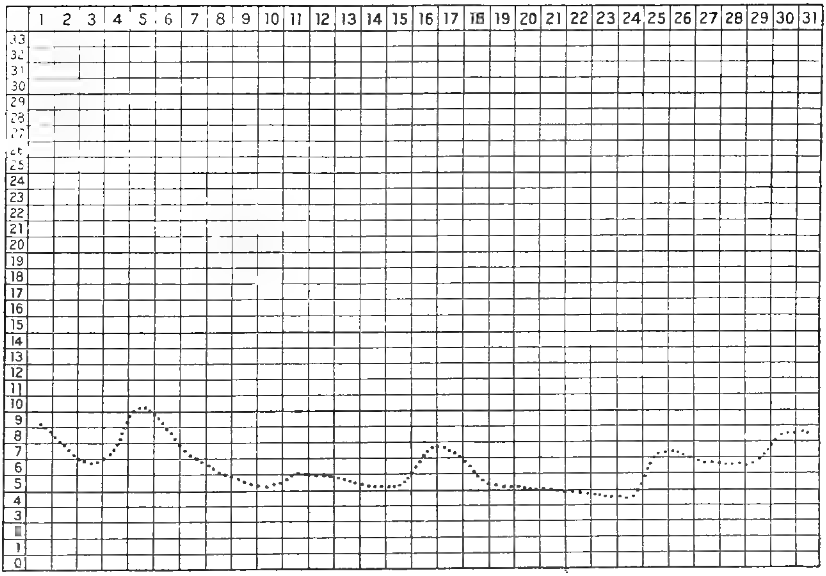
At Geneva, Nebr., where the subsoiling had been thoroughly done some time before the observations were commenced, and where the soil had been thoroughly wet by subsequent rains, the amount of moisture has been materially greater throughout the season than under ordinary conditions of cultivation.

WHAT THE DIAGRAMS MEAN.

In the illustrations the vertical columns mark the days of the month, as indicated by the figures at the top of the diagram. The horizontal lines running across the diagram represent the percentage of moisture in the soil, as indicated in the column of figures on the left-hand side of the illustration, extending from 0 to 33 per cent. As a guide to the eye, the lines representing every 5 per cent of moisture are made heavier.

The records for each day of the month are put upon the form in their appropriate places. Thus, if on the first day of the month there is 8 per cent of moisture in the soil, a mark is placed in the column representing that day at a height corresponding to the figure 8 on the left-hand side of the page. If on the next day there is 12 per cent of moisture in the soil, a mark is made in the next column at a height corresponding with the figure 12, and so on for each day of the month. When these marks have all been placed, a permanent line is drawn through each of them, giving a more or less curved line according to the daily differences in the water contained in the soil. The marks are then rubbed out, and the curved line shows the monthly record. Where it is stated that there is 10 per cent of moisture in the soil, it means that on that date 10 per cent, or one-tenth of the weight of the soil in its natural position in the field to a depth of one foot from the surface, is water. When 20 per cent of water is present, it means that 20 per cent, or one-fifth of the weight of the soil as it lies in the field, is water. No crops were allowed to grow on any of the plats except two in sod land and four in prairie sod.

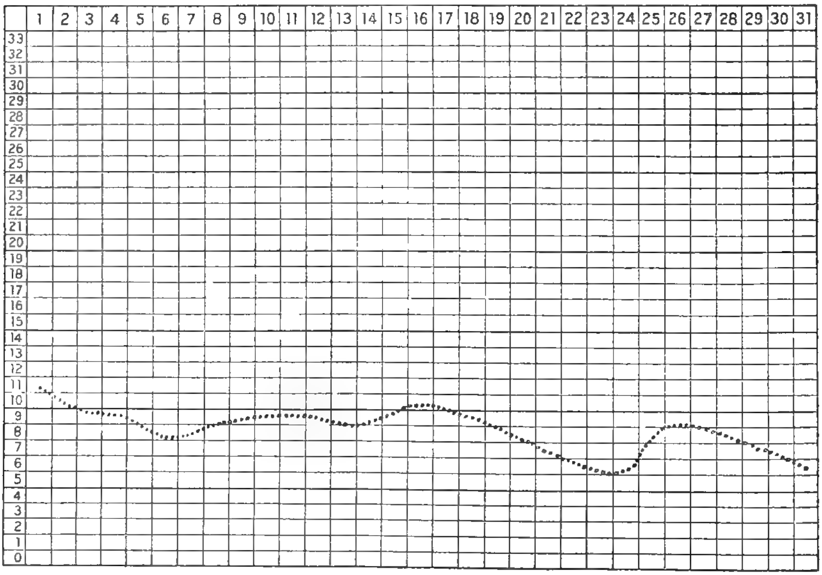
MARDELA SPRINGS, MD.



Early truck land ....

During the early part of the month the surface was rather too wet to cultivate. From July 5 to 10 the conditions were reported as favorable; from then until the 15th the soil was reported as too dry for crops. On the 16th about one-third of an inch of rain fell and benefited crops, but from July 18 to 24 the crops were reported as again suffering from lack of moisture. On July 25 1 inch of rain fell, making the surface too wet for cultivation. On July 27 the surface was dry and the crops were reported as again suffering for rain.

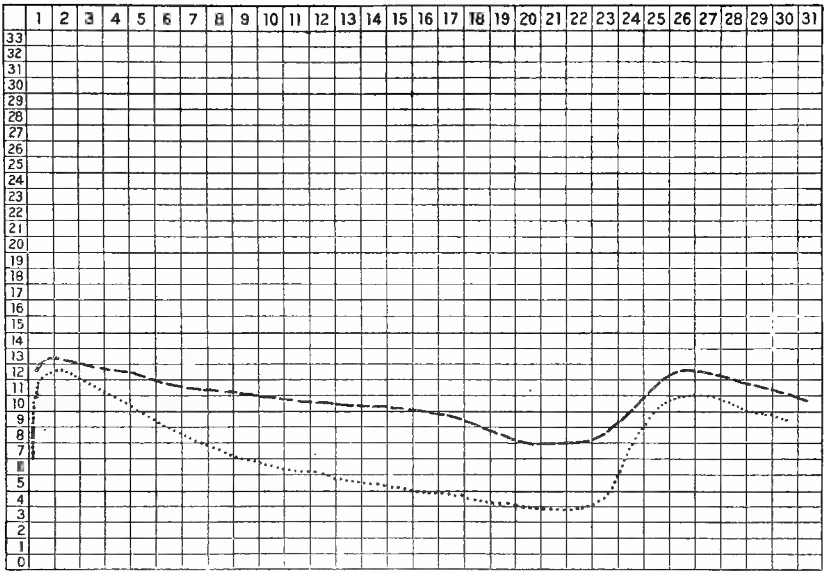
TOANO, VA.



Early truck land ....

The soil conditions were reported as generally favorable throughout the month for truck crops. On July 5 potatoes had matured and melons were in bloom, while other of the early truck crops were being harvested.

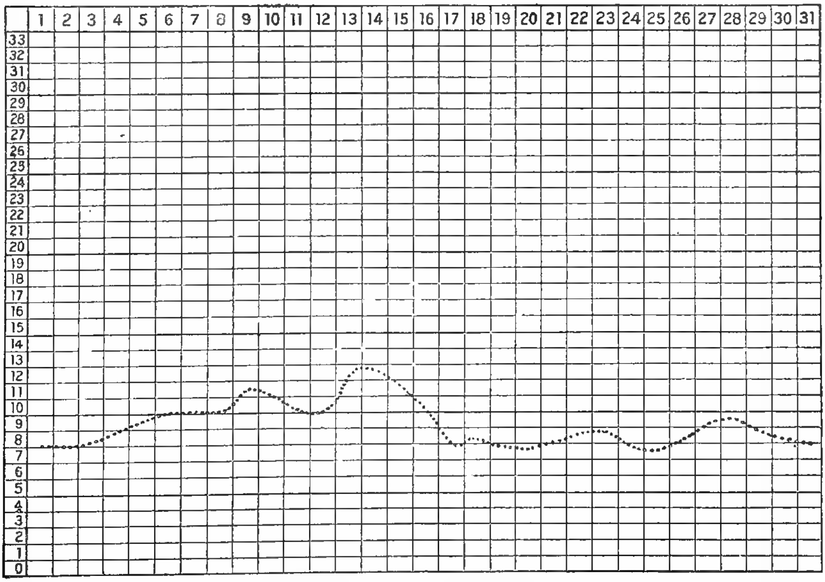
OXFORD, N. C.



Uncultivated .... Cultivated and with crop growing on land ▬▬▬

This soil was very dry during the last week in June and the tobacco was suffering for lack of rain. A good rain occurred on July 1, which greatly benefited the tobacco crop. The conditions continued extremely favorable throughout the month, except that from July 20 to 24 they were reported as rather too dry. It will be seen from these records that in the tobacco field under actual cultivation there has been from 1 to 6 per cent more moisture than in the uncultivated land, notwithstanding the fact that the growing plants must have transpired great quantities of water. The effect of cultivation in conserving the moisture is thus made very apparent in the gradual fall of the moisture curve as compared with the more abrupt descent of the curve representing the moisture conditions in the uncultivated land. For fifteen days, with no appreciable rainfall, there was maintained, through cultivation, from 4 to 6 per cent more moisture, or nearly twice as much, in the cultivated field as in the uncultivated.

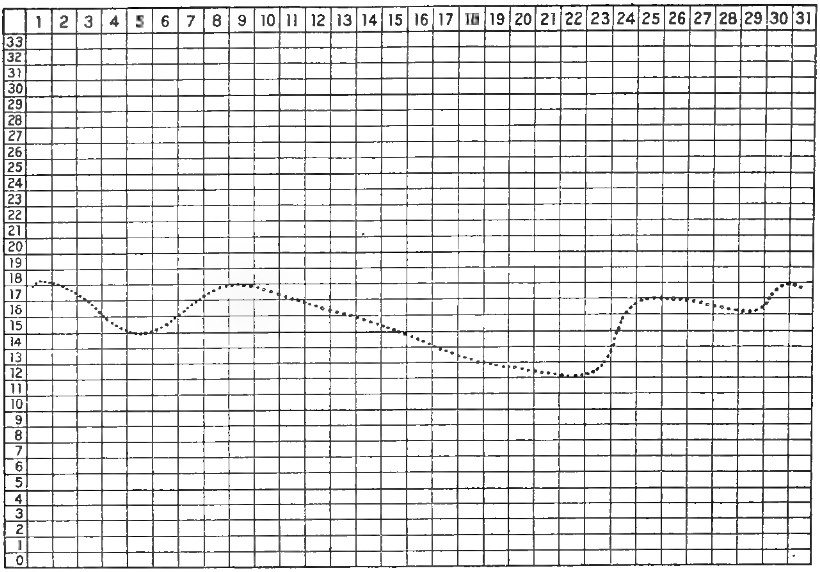
POQUONOCK, CONN.



Cultivated land bare of vegetation ....

These records are from a typical tobacco soil of the Connecticut Valley, adapted to the Sumatra type of cigar wrappers. The conditions throughout the month were reported as extremely favorable.

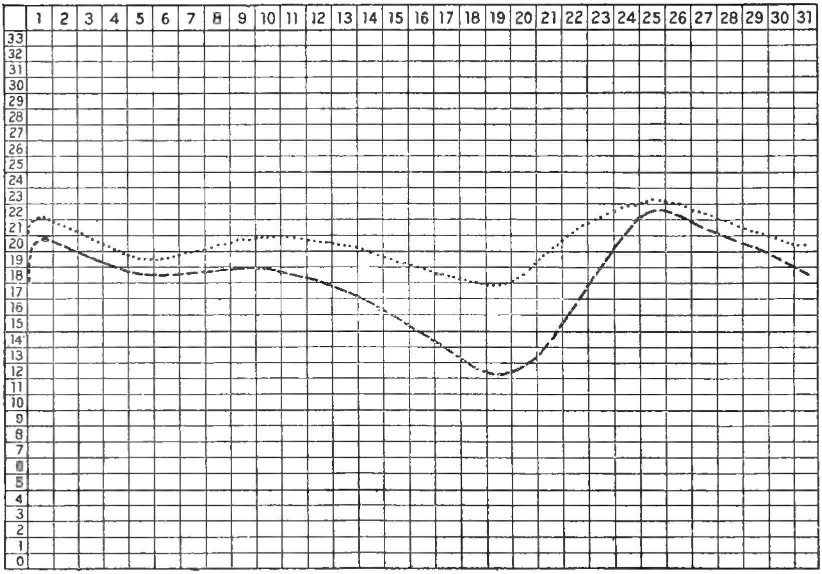
NEWSTEAD, KY.



Dark shipping-tobacco land ....

Conditions reported as very favorable for tobacco. From July 24 to 31 the surface was reported as too wet for cultivation.

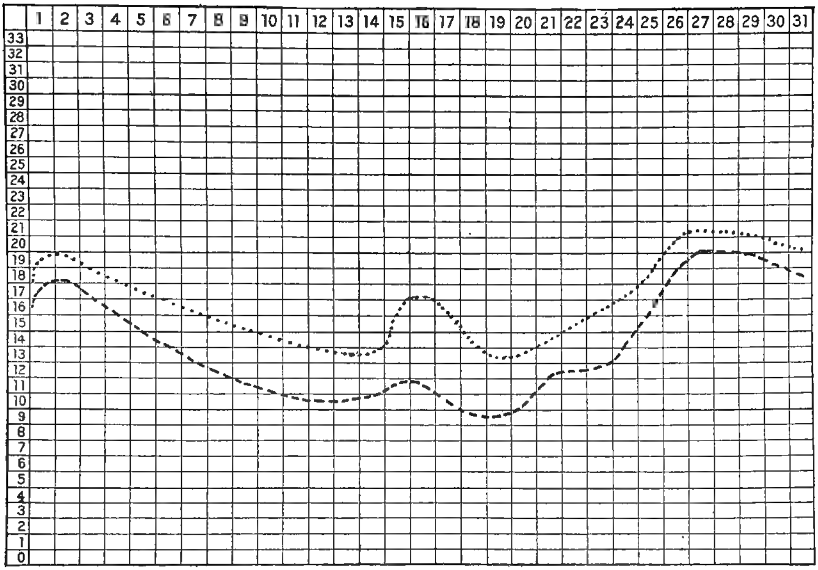
LEXINGTON, KY.



Uncultivated .... Grass land ▬ ▬ ▬ ▬

These records have been discussed on a previous page. The conditions were generally favorable for the pasture grasses, except from July 17 to 20, when the conditions were reported as rather dry. As in June, the grass is seen to be a great drain upon the soil moisture throughout the month.

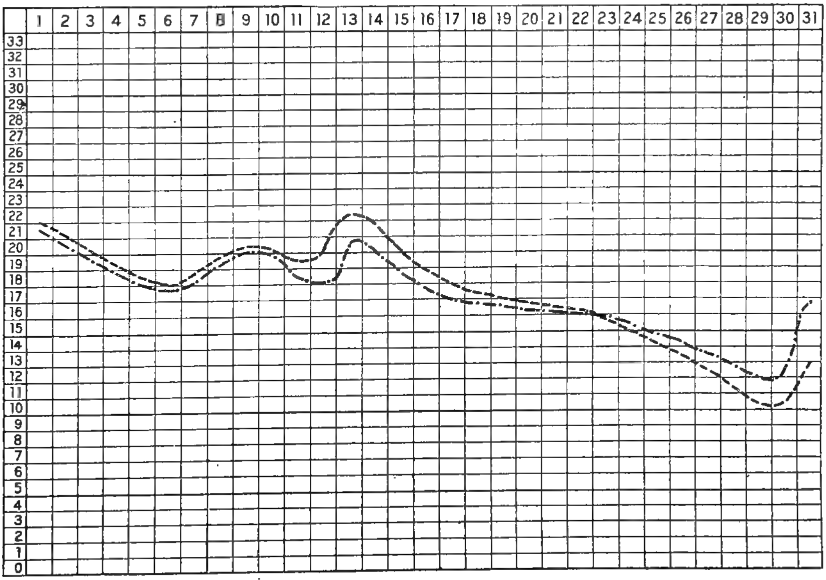
GREENDALE, KY.



Uncultivated........ Grass land ▬▬▬▬

Conditions reported are similar to those at Lexington. They were generally favorable except during the middle of the month, which was reported as too dry.

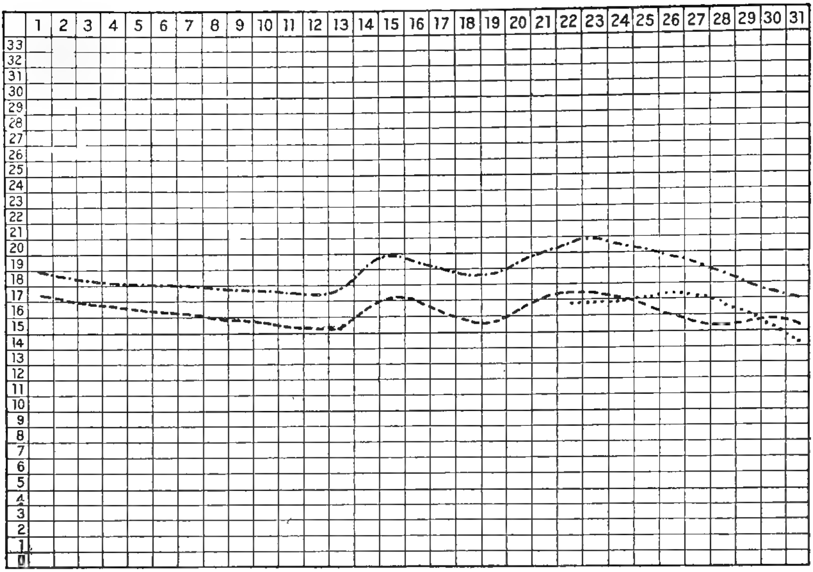
WELLINGTON, KANS.



Cultivated ▬▬▬▬ Subsoiled ▬·▬·▬

The conditions were reported as generally extremely favorable, except during the last week of July, when the soil was reported as being too dry. As stated in Bulletin No. 1, the subsoiling at this place was done during the very dry season immediately preceding the commencement of the observations. For these reasons it was not very effectually done, and it was some time after the subsoiling had been done before the rain of June 1 ended the prolonged drought which had been in progress.

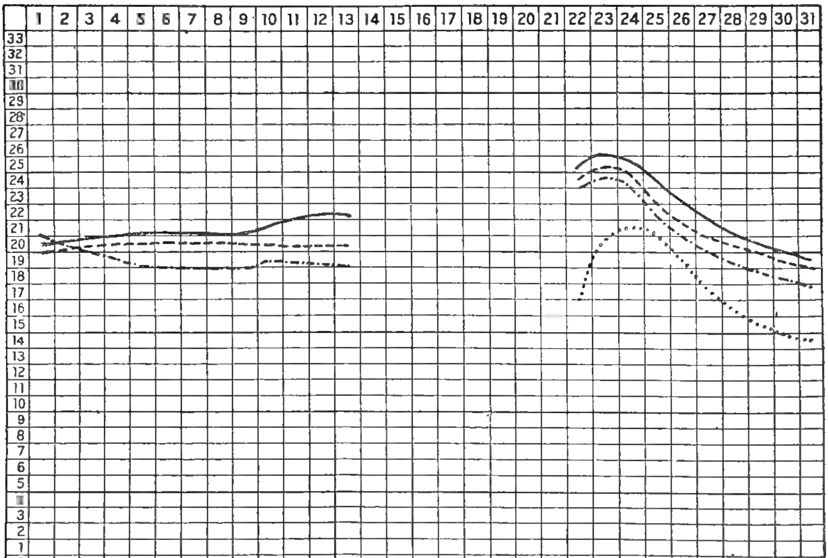
PHILLIPSBURG, KANS.



Uncultivated .... Cultivated ▬ ▬ ▬ ▬ Subsoiled ▬ . ▬ . ▬ .

The conditions were reported as extremely favorable throughout the month, as frequent showers prevailed, and there was quite a rank growth of vegetation. On the last day of the month the conditions were reported as rather dry, from the dry, hot weather which was then prevailing. On that date the upland corn was reported to be slightly burned; most of the wheat had been harvested. The subsoiled field shows uniformly from 1 to 3 per cent more moisture than the soil under ordinary cultivation.

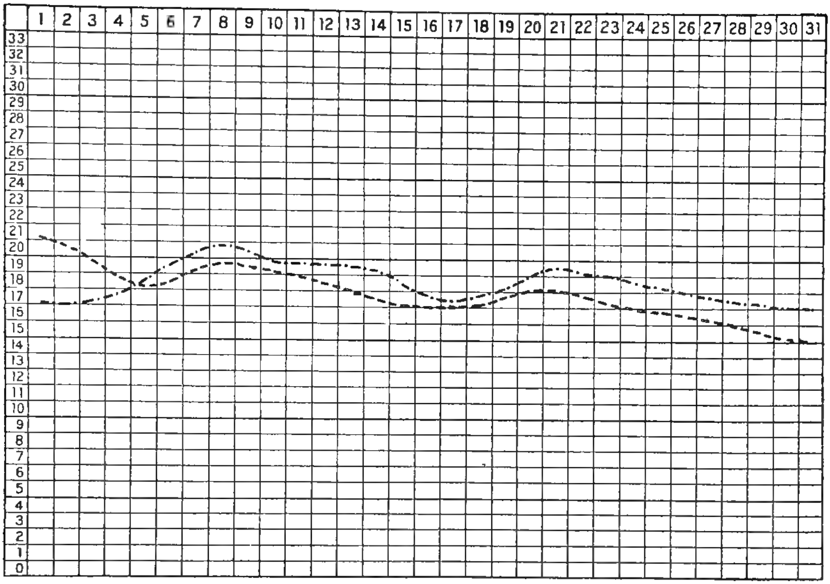
SCOTT, KANS.



Prairie sod .... Cultivated ▬ ▬ ▬ ▬ Subsoiled ▬ . ▬ . ▬ Irrigated ▬▬▬▬

The conditions were reported as very favorable during the first part of the month. On July 22 to 23, 2½ inches of rain fell, which thoroughly soaked the ground and delayed the already late harvest. Wheat harvesting began on July 26, and the yield was considered an average yield for that locality.

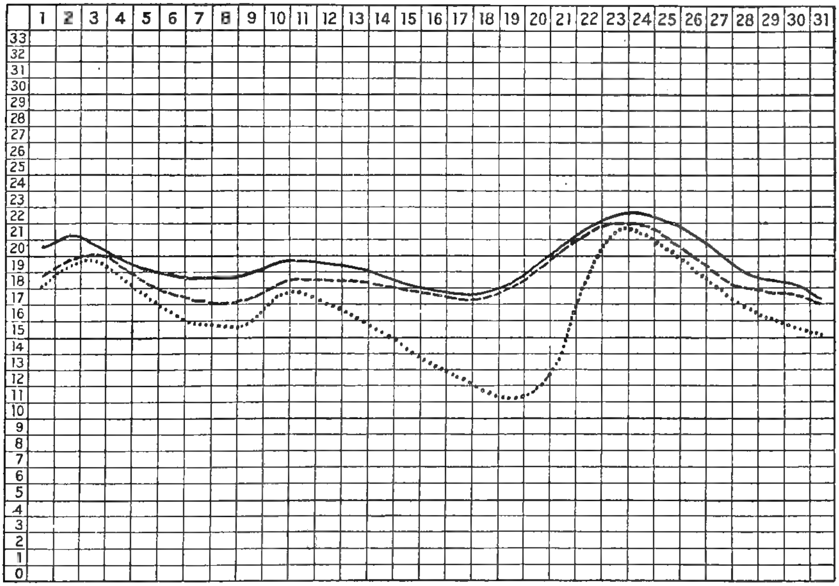
HAVEN, KANS.



Cultivated ▬▬▬▬ Subsoiled ▬·▬·▬

The conditions were reported as very favorable throughout the month, except that immediately after the frequent rains the surface was rather too wet for working.

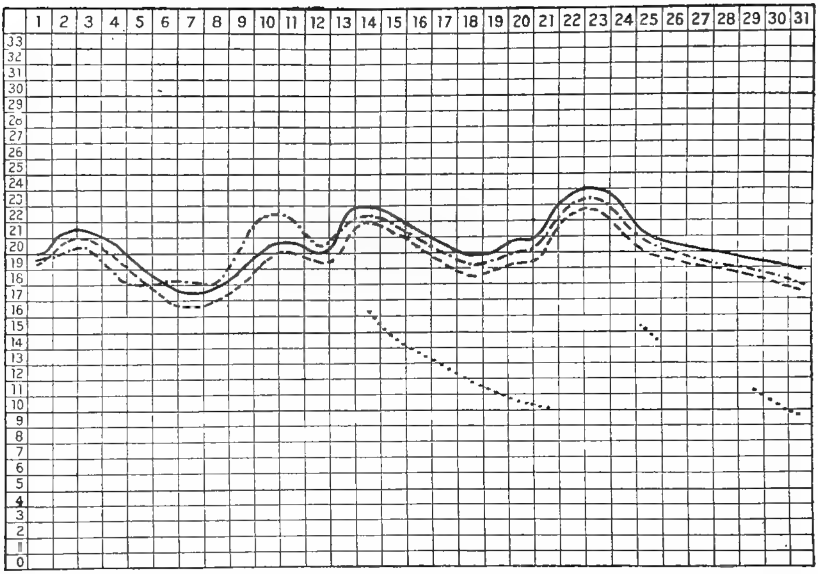
GARDEN CITY, KANS.



Uncultivated .... Cultivated ▬▬▬▬ Irrigated ▬▬▬▬▬

The conditions were extremely favorable throughout the month, and irrigation was not needed, as the cultivated field was sufficiently moist throughout the period for the need of the crops. The season was exceptionally favorable for this locality and for this season of the year.

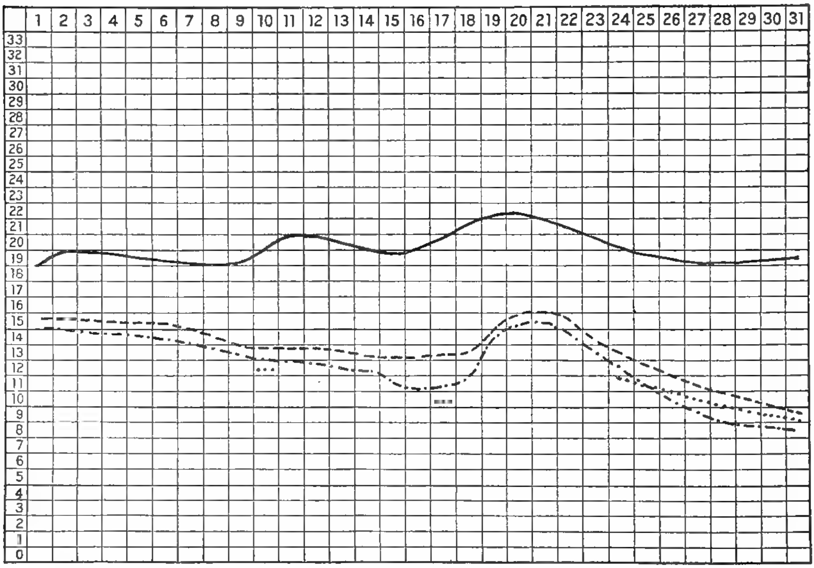
COLBY, KANS.



Prairie sod......... Cultivated ▬▬▬▬ Subsoiled ▪▬▪▬▪ Irrigated ▬▬▬▬

The conditions were reported as very favorable for the staple crops during the month, with frequent rains. The conditions in all the cultivated plots were quite uniform, but the few records of the moisture under the prairie sod show a very marked effect of cultivation in conserving the moisture at this place.

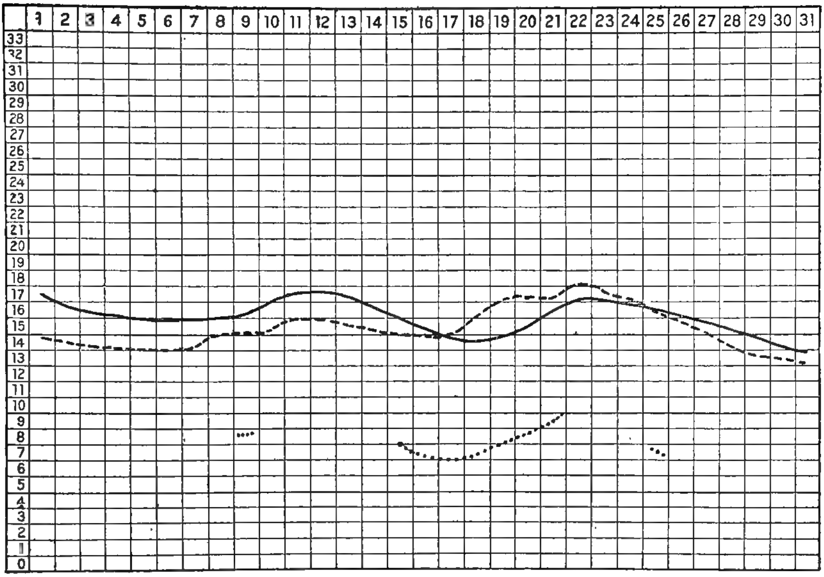
STAFFORD, KANS.



Uncultivated .... Cultivated ▬▬▬▬ Subsoiled ▪▬▪▬▪ Irrigated ▬▬▬▬

The soil conditions were reported as generally favorable throughout the month, except on the last three days, when they were reported as too dry. Irrigation was resorted to on the irrigated plot, and water was applied July 1 and 10. It is seen that the moisture curve for the irrigated field is from 4 to 8 per cent higher than in any of the fields under dry farming. No crops were growing on any of these plots, but the yield of potatoes on the adjoining irrigated field was said to have averaged about 160 bushels per acre. The soil at this place is said to be underlaid with a hardpan, and the conditions are such that there is seldom a full crop upon the locality where these samples have been taken except under irrigation.

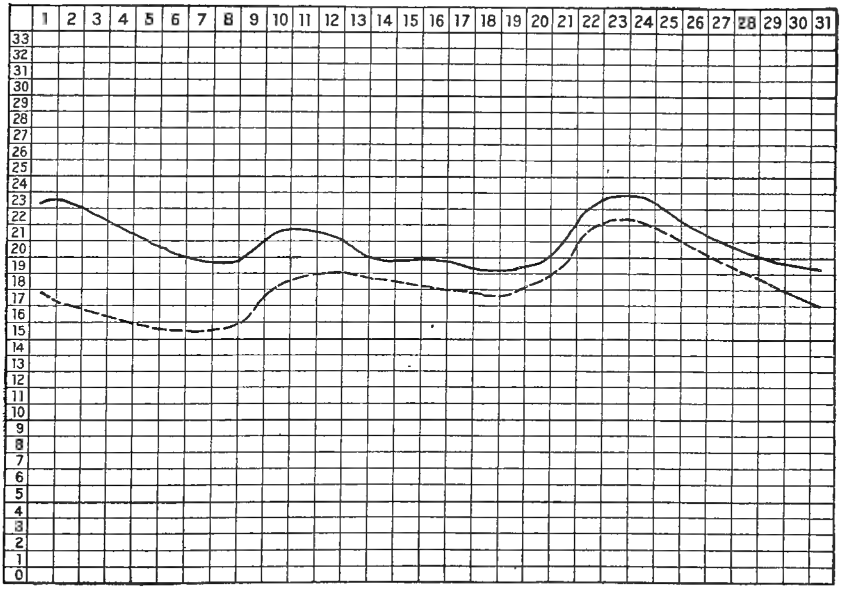
ELLINWOOD, KANS.



Prairie sod .... Cultivated ▬ ▬ ▬ ▬ Irrigated ▬▬▬▬

The conditions were not as favorable at this place as were those at other places in Kansas from which reports were received. The conditions were too dry during most of the month. The observer does not report the application of water to the irrigated plot and the records do not indicate its use. This soil is rather light in texture and requires frequent rains to maintain a proper water content. A few observations taken in the prairie sod show that the effect of ordinary cultivation was to maintain twice as much moisture in the soil as is contained under the prairie sod.

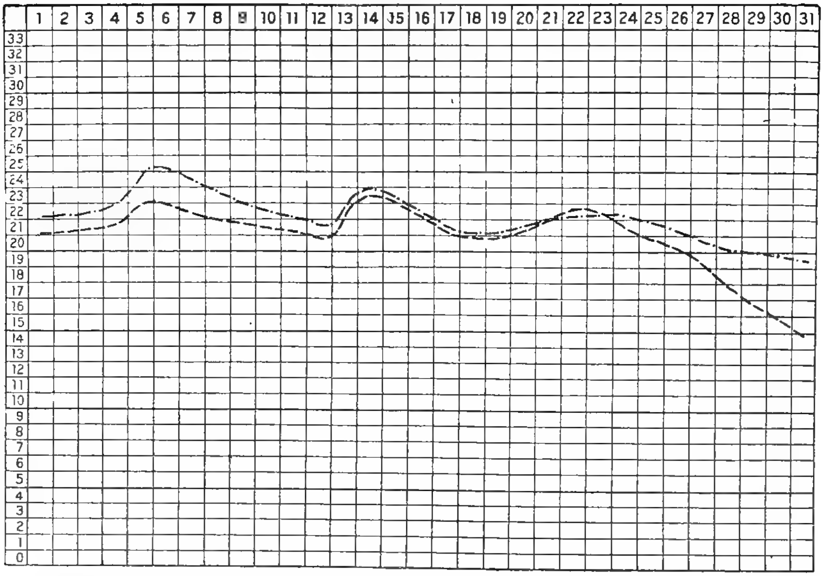
FOWLER, KANS.



Cultivated ▬ ▬ ▬ ▬ Irrigated ▬▬▬▬

The conditions were reported as very favorable throughout the month, with frequent showers, giving an excellent prospect for crops.

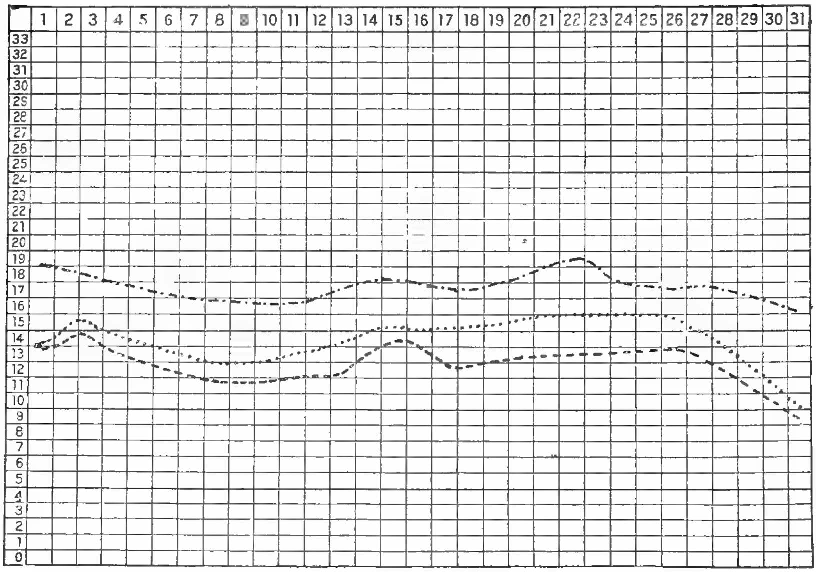
MANKATO, KANS.



Cultivated ▬▬▬▬ Subsoiled ▬·▬·▬

The first part of the month the weather was hot and sultry, with frequent showers. Crops were reported in a very flourishing condition until the 25th, when hot winds commenced and continued at intervals during the rest of the month, causing considerable damage to the corn crop. The records appear to show that the field under ordinary cultivation lost more moisture from these hot winds than that which had been subsoiled.

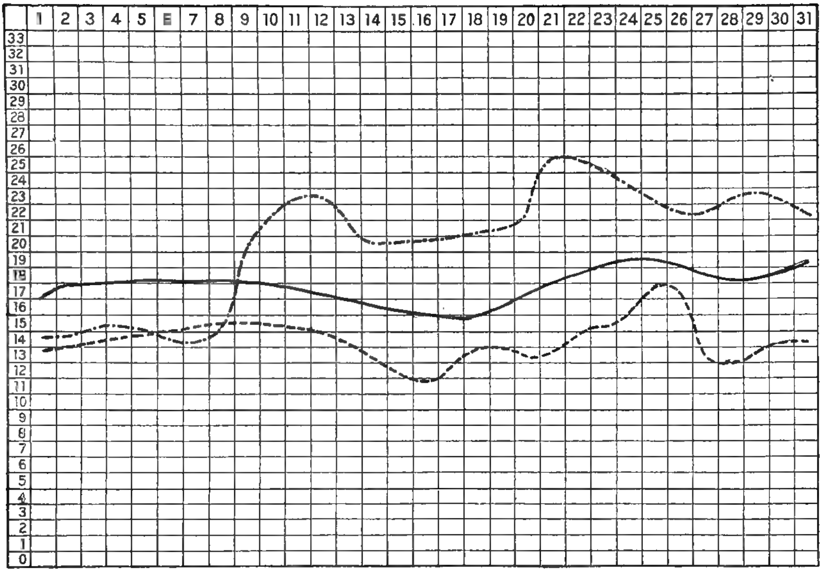
GENEVA, NEBR.



Prairie sod .... Cultivated ▬▬▬▬ Subsoiled ▬·▬·▬

Very meager reports were received of the conditions at Geneva, except that there was a dry period during the first third of the month. As was pointed out in the May and June records, this is the only place from which records have been taken from subsoiled fields where the subsoiling had been done a sufficient length of time before the observations commenced to insure a thorough soaking of the land. The effect of the subsoiling upon the water content of the soil has been very marked throughout the season. During this month there was from 2 to 4 per cent more moisture in the subsoiled field than under the prairie sod, while the field under ordinary conditions of cultivation which prevailed in that locality appears to have even less moisture than was found under the prairie sod.

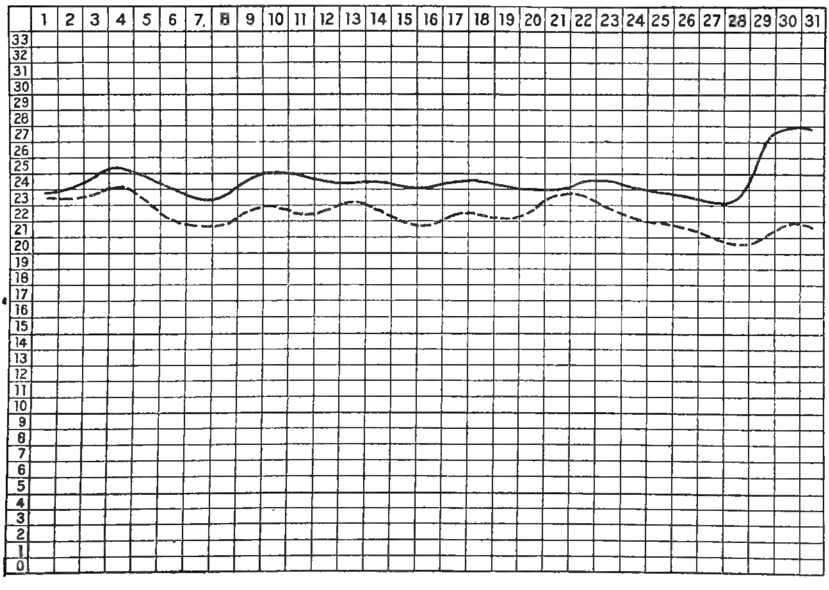
BIG SPRINGS, NEBR.



Cultivated ▬▬▬ Subsoiled -·-·- Irrigated ———

The conditions were reported as generally very favorable during the month, with a prospect of an excellent corn crop on the irrigated land, and from one-fourth to one-half a normal yield of crop on the land under ordinary conditions of cultivation. The records from the subsoiled field are quite irregular, and appear to show a much higher water content than from either of the other plots. The subsoiled plot appears to be very uneven in character.

NORTH PLATTE, NEBR.



Cultivated .... Irrigated ———.

Conditions were reported as generally very favorable throughout the month. These records were taken from a bottom land, which probably accounts for the very high water content shown at this place throughout the season.

BULLETIN NO. 4. A. S. 6.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF AGRICULTURAL SOILS.

METHODS

OF THE

MECHANICAL ANALYSIS OF SOILS

AND OF THE

DETERMINATION OF THE AMOUNT OF MOISTURE IN SOILS IN THE FIELD.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1896.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF AGRICULTURAL SOILS,
Washington, D. C., February 15, 1896.

SIR: I have the honor to transmit herewith a manuscript describing the methods in use in this Division for the mechanical analysis of soils and for the determination of the amount of moisture in arable soils.

This is intended partly for the instruction of the observers and special agents of this Division, and partly for the information of workers in the agricultural colleges and experiment stations and other institutions or organizations which are interested in similar lines of work and who wish specific information as to methods.

I recommend that this be published as Bulletin No. 4 of this Division.

Respectfully,

MILTON WHITNEY,
Chief of Division.

Hon. J. STERLING MORTON,
Secretary of Agriculture.

CONTENTS.

MECHANICAL ANALYSIS OF SOILS.

COLLECTING SAMPLES OF SOIL FROM THE FIELD.

The methods of collecting samples of soil should depend largely upon the nature of the work for which the sample is to be used. The purpose of this Division is to investigate the texture and physical properties and conditions of the soils of extensive agricultural areas and to establish the typical conditions prevailing therein which adapt them to certain crops or certain agricultural interests. Having established these general conditions as a basis for the study and classification of soils, it remains for local institutions to investigate soils of local interest in their respective States.

As a rule, then, it is necessary that the soils selected for examination or investigation by this Division should represent large areas of land of uniform composition and of similar agricultural value, and not merely a small area in which the observer is particularly interested. These conditions may be determined from native growths, or from cultivated crops, or from the general appearance of the land. For instance, in a wheat, corn, tobacco, or truck area the samples selected should represent the best type of land for those crops.

It is often advisable also to study soils and soil conditions unadapted to our present agricultural crops. Many large areas of land are at present barren and unproductive, and, under certain circumstances, it is advisable to investigate the texture and moisture conditions in these tracts.

These investigations are intended as permanent records of the typical conditions of the principal soil areas of the United States and the relative proportions of moisture which the soils maintain under prevailing climatic conditions.

WHERE SAMPLES SHOULD BE TAKEN.

In order that every sample may represent the area or a certain part of the area which it is desired to study, it must not be taken where there are modifications due to local conditions. It is better, where possible, to take the samples from cultivated fields, or fields which have been cultivated. The agricultural value of such land is known from the character of the crop it has produced, and this is a very important guide in the selection of typical soil samples. In the older agricultural regions of the Eastern United States, especially in the most fertile soil areas, there is little or no virgin land and often little woodland. Where the trees are allowed to grow, it frequently happens that it is on some spot or area which has been abandoned for some local cause or which has never been brought under cultivation because of its small agricultural value. A sample taken in such uncultivated spots would not represent the typical soil area of the locality, whereas soil which has been under cultivation carries a record in its crop yield and in the character of the crop produced, which is an important guide in the classification of the lands.

The samples should be taken inside a field, some distance away from houses, fences, roads, or trees. If plants are growing in the field, the sample should be taken midway between two plants. They should not be taken where the soil has been eroded nor where the soil has accumulated to an unusual depth by washing from above. It is doubtless better to take the samples from land which has not been freshly manured or where fertilizers have not been recently applied, but if there is no such field available this need not prevent the taking of samples, for the purpose of the investigation is to study the conditions under which the plants are growing in the field under the ordinary operations of the farm.

For the study of local conditions, such as the soil of a single field or a single farm, samples should be taken from five to eight localities, at some distance from each other, according to the uniform character of the soil, thoroughly mixed together if the land appears uniform, and a small sample of this mixture taken to represent the average conditions of the field. If the land appears not to be uniform, the samples should be kept separate and examined separately. In the work of this Division, however, great soil areas of nearly uniform conditions are being studied and samples are taken over wide areas, irrespective even of State lines. A single sample may be sufficient from any one field, provided a sufficient number of widely separate localities are examined from the same formation, to give a basis for an estimation of the uniform character of the formation and to judge as to whether each individual sample represents truly the type of soil which it is desired to study.

The type having been established, a single sample, selected with care and judgment, is usually sufficient to determine whether the soil of that locality corresponds to the typical soil formation which it is desired to study.

HOW SAMPLES SHOULD BE TAKEN.

Having selected the spot in conformity with the above instructions, there are two reliable methods for collecting the samples—with a spade and with an auger. To collect the sample with a spade, remove all grass, leaves, or litter from the surface and dig a hole like a post hole 24 inches deep. Scrape the sides clean and notice the depth at which the change of color occurs between the soil and the subsoil. Take a sample of the soil above this by cutting off a slice of soil 3 or 4 inches thick, down to the change of color, and mix this thoroughly together. Fill a cloth sack with this well-mixed soil, tie it securely, and label it with such information as will serve to identify it when it is received in the laboratory. Then clean out the hole again and scrape the sides so as to get rid of every particle of the top soil, and take a sample of the subsoil in like manner by cutting down a slice of the subsoil and thoroughly mixing it together so that the sample shall contain particles of the subsoil from immediately below the top soil to a depth of at least 24 inches. Put this sample of the subsoil into a separate sack, tie it securely, and label it. If there is no apparent difference between the soil and the subsoil, take a sample of the soil nevertheless to a depth of 6 inches from the surface, and a sample of the subsoil from below this to a depth of 24 inches, and put them into separate sacks as above. If the character of the subsoil materially changes before the depth of 24 inches is reached, a separate sample of this changed material should be taken and the depth noted at which the change occurs.

To collect samples with an auger, take a common wood auger from 1½ inches to 3 inches in diameter and have the handle lengthened to 24 or 30 inches. Remove the litter and grass as before from the surface of the field, and bore into the soil, pulling up the auger and emptying the sample into a sack for every 3 or 4 inches in depth. The depth of the top soil should be determined by a preliminary boring. Care must be taken to separate the top soil from the subsoil and to keep them in separate sacks. If there is a marked difference in the character of the subsoil within 18 or 20 inches of the surface, a separate sample should be taken of the second subsoil, the depth of each being carefully noted.

IMPORTANCE OF TAKING SAMPLES AT UNIFORM DEPTHS.

It is very important that the samples be taken, as far as practicable, to a uniform depth, to secure the greatest comparative value in the work. The plan adopted by this Division is to take the sample of top soil to a depth of at least 4 or 6 inches, or to the change of color where this is apparent within 9 or 12 inches of the surface. The subsoil is then sampled to a depth of at least 24 inches in the case of very stiff clays, and to a depth of 24 or 30 inches in the lighter soils.

An idea of the importance of taking samples to a uniform depth and of stating this depth may be seen from the following table of mechanical analyses of samples of the Kentucky blue-grass land from Lexington, Ky. The samples were taken from a vertical hole, one directly under the other, at the depths shown in the table:

Mechanical analyses of Kentucky blue-grass soil.

Diameter (mm.).	Conventional names.	295 (0–6 in.).	296 (6–12 in.).	297 (12–18 in.).	298 (18–24 in.).
2–1	Gravel	0.00	0.00	0.00	0.00
1–.5	Coarse sand	0.00	0.11	0.00	0.00
.5–.25	Medium sand	0.14	0.12	0.11	0.07
.25–.1	Fine sand	0.28	0.16	0.15	0.11
.1–.05	Very fine sand	1.35	2.49	0.61	0.33
.05–.01	Silt	48.72	40.63	40.44	33.45
.01–.005	Fine silt	15.26	16.12	15.53	13.00
.005–.0001	Clay	25.49	33.42	37.28	44.95
		91.24	93.05	94.14	91.91
	Organic matter, water, loss	8.76	6.95	5.86	8.09

It will be seen that the percentage of clay is very different at these different depths, and the results of the analyses would have been very different in two samples taken side by side at different depths. It occasionally happens from the nature of the subsoil that the samples can not be taken to a depth of 24 to 30 inches. In any case, the actual depth represented by each sample should be stated—such as "0 to 6 inches;" "6 to 24 inches"—and a note made of the character of the sample.

SACKS FOR COLLECTING SOIL SAMPLES.

Three sizes of sacks are used by this Division for the collection of soil samples. When the samples are taken with a spade, 8 to 10 pounds of material should be collected and put into a cloth sack—14 by 8½ inches—of heavy, unbleached muslin. For samples taken with the auger, a smaller sack can be used, as the sampling is usually more accurately done. Sacks 6 by 8½ inches are very convenient for this purpose. As the sample of the top soil is usually smaller than that of the subsoil, and as it is usually of relatively less importance, smaller sacks, 4 by 6 inches, may be conveniently used for the sample of top (surface) soil. This is likewise a very convenient size to take on an expedition when a large number of samples are to be taken and when the weight of material is an important consideration. These sacks have short pieces of string or tape sewed to them for convenience in tying, and they should each be numbered with a stencil for convenience in referring to them in the field notes.

Each sample should be carefully labeled on a tag prepared for the purpose, to be tied to the sack. This may be conveniently printed on one side of a shipping tag, with the name of the institution or individual printed in bold-faced type on the other side. The samples are heavy and bulky, and are usually moist, so that it requires a very strong and tough tag to stand the wear. It is important to use either linen tags or the tough red express tags.

FORMS FOR DESCRIPTION OF SAMPLES.

The following form has been adopted for use by this Division where samples are sent in by field agents of the Department or by farmers:

Locality:	
No. of sack: Date: Collector:	Description of land: (a) Virgin or cultivated? (b) Natural herbage: (c) Class of crops best adapted to land (grass, wheat, corn, tobacco, truck, barren):
Depth of sample: Soil or subsoil? ....in. to....ins.	Geological formation:

In sampling with the auger in a locality or in a formation which is already known, and where the samples are taken with great care, smaller tags may be conveniently used, there being less information to be added in the field. The following form is used for this purpose by this Division:

Name...

Locality...

Type (grass, wheat, corn, tobacco, truck, barren land).

Depth of sample, ... in. to .... ins.

Character of sample ....

....

Geological formation...

No. of sack ....

When the samples are sent from a locality which has not been carefully examined by agents of the Department, a very full report should be made to supplement that contained on the shipping tags. This should include the character of the soil and the staple crops which have been successfully grown upon it; the yield of the principal crops; the character of the crops; the effect unfavorable seasons have upon the crop. In a wet season are the plants liable to make an abnormal development? Are they subject to diseases? Does a dry season reduce the yield of the crop materially? Does it affect the quality of the crop? All the information bearing upon the relation of the soil to crops in different seasons should be given, so as to make possible an intelligent diagnosis of the soil conditions and throw light upon any peculiarities which are manifested either in the actual relation of soils to crops in the field or in the laboratory examination of the samples. Such information, besides, may often point to causes controlling crop production apart from those existing in the soil and shown in the sample. As in the case of a sufferer from headache, the cause of the trouble may not be in the head at all, but in some other part of the body, so, in like manner, unfavorable conditions may actually exist in the soil, due to extraneous conditions which would not be indicated in an examination of the samples.

METHOD OF THE MECHANICAL ANALYSIS OF SOILS.

The method used for the mechanical analysis of soils in this Division is Osborne's beaker method, described in the Annual Reports of the Connecticut Experiment Station for 1886 and 1887, with such modifications as experience has suggested for rapid work in the examination of large numbers of samples.

PREPARATION OF THE SAMPLES.

Samples of soil, when received in the laboratory, are spread out in a thin layer and dried at the ordinary temperature of the room. When air dry, they are put into half-gallon preserve jars and stored for future work. In taking a subsample of this for a mechanical analysis, the whole sample is emptied from the jar and thoroughly mixed together on a sheet of heavy manila paper—or better, on a piece of oilcloth. If there are lumps, these are broken with a wooden mallet or with an ordinary wooden rolling-pin. Roots and litter of all kind are thrown away, if they can readily be picked out by hand. Gravel and stones are separated, if present, by passing the material through a brass sieve with circular holes 2 mm. in diameter. These stones are washed, dried, and weighed, and the weight deducted from the original weight of the sample and the percentage of coarse gravel calculated. The portion which has passed through the 2 mm. sieve is called the "fine earth," and is used for the mechanical analysis. The fine earth is thoroughly mixed together, spread out in a thin layer, and a small sample taken from different parts of it and put into a subsample bottle. Twenty grams of this air-dry material are taken for a mechanical analysis and 5 grams for the determination of moisture and organic matter.

METHOD OF DETERMINING THE AMOUNT OF MOISTURE AND ORGANIC MATTER.

Five grams of the air-dry sample are put into a platinum crucible or dish and dried at 110° C. for two hours or to a constant weight. The loss in weight is taken to represent the amount of moisture in the air-dry sample, unless the sample contains a large amount of carbonate of lime, in which case an allowance has to be made for the decomposition of the carbonate, and the moisture determination is very troublesome.

The sample, after being dried to determine the amount of moisture, is used for the determination of the organic matter. For this purpose it should be subjected to a low red heat until all the organic matter has been oxidized, which can usually be determined by the change of color. The loss in weight during the ignition is taken to represent the organic matter. When there are carbonates present, the sample has to be quite strongly ignited to decompose these completely and the amount of carbonic acid determined in a separate sample.

METHOD OF MECHANICAL ANALYSIS.

It is essential that the mass of soil should be thoroughly disintegrated and the grains separated from each other. This may be accomplished by one of two methods or by a combination of the two.

Twenty grams of soil are moistened with distilled water so as to make a very thin paste. This is gently rubbed in a porcelain mortar with a rubber-tipped pestle until the mass is thoroughly disintegrated and the grains do not cling together. The rubber tip used in this Division is such as is used on crutches and canes, which is easily slipped onto the small end of an ordinary porcelain pestle. In rubbing there should be just enough pressure to detach adhering particles, not enough to break the grains. After pestling for ten or fifteen minutes, more water may be added, and after letting it stand a few moments the turbid liquid may be decanted into a beaker and fresh water added to the soil in the mortar and the pestling continued until a microscopic examination shows that the mass has been thoroughly disintegrated.

Pestling requires a considerable amount of time, and where there are a large number of samples to be done it is much easier to attain the same results by shaking the soils for a long time in water. For this purpose the bottles used in sterilizing milk for infants are very convenient. The 20 grams of soil are washed into such a bottle and the bottle about half filled with distilled water. The bottle is closed with a rubber stopper and put into a shaking machine. The form of shaker used in this Division is very simply constructed. It consists of a box with compartments for holding four tiers of bottles lying on their sides, allowing four bottles in each compartment. This box is supported by chains, attached to the corners, hanging from brackets above. It is fastened by rubber bands to the table below, to steady it, and a guide rod is fastened to the bottom, which works between two uprights to give a true lateral motion to the box. The box is then moved rapidly back and forth by a crank, with a throw of about 5 inches, at a rate of about 170 revolutions per minute. This gives a very good motion to the liquids in the bottles and keeps the soil constantly agitated. Motion may be imparted to the shaker by a water motor or other suitable power. The shaking is continued for from one to two days, according to the nature of the sample. The heavier clay soils require the longer time. The shaking can be done, of course, without any personal attention on the part of the operator, and it is advisable to start the samples shaking long enough before they are needed, so that there shall be no interruption in the work.

When the shaking is stopped, the contents of the bottles are washed into beakers and the sediment, which quickly subsides, is examined with the microscope. If the disintegration is not complete, a small amount of pestling with the rubber-tipped pestle will finish it. Usually sandy soils are very thoroughly disintegrated after being shaken a day, while clay soils frequently require pestling after having been shaken for two days.

When clean, the grains should show sharp outlines under the microscope, being as a rule quite transparent. Adhering particles make them appear rounded and more or less deeply colored and the outlines indistinct. When pestling alone is resorted to for this disintegration of the material, it may require from fifteen minutes to an hour or more, depending upon the nature of the sample.

When the material is thoroughly disintegrated, it is transferred to a 3-inch beaker, which we may call S. This is filled with water and thoroughly stirred. It is then allowed to settle until all solid particles larger than 0.05 mm. have subsided. This is determined by taking a sample of the turbid liquid from near the bottom of the beaker by lowering a small tube, with the top closed by the finger, to a point just above the sediment, then removing the finger for an instant and letting the liquid enter the tube, closing the tube with the finger again and withdrawing the sample. A drop of this is placed upon a microscope slide and a cover glass placed over it and the particles examined by a good microscope containing an eyepiece micrometer. It is convenient to use a 1-inch eyepiece and a three-fourths and one-fifth inch objective. With the microscope used in this Division the 1-inch eyepiece and $\frac{3}{4}$-inch objective, three of the 0.1 mm. spaces of the eyepiece micrometer measure 0.05 mm. on the stage. With the same eyepiece and the $\frac{1}{5}$-inch objective, two spaces of the micrometer are equal to 0.01 mm., and one space to 0.005 mm. These three values are sufficient for the beaker separations.

When the particles larger than 0.05 mm. have subsided, the turbid liquid is carefully decanted into a larger beaker, M. This turbid liquid contains silt, fine silt, and clay, but no sand if the separation has been properly timed. The sediment in S consists of sand, containing still some silt, fine silt, and clay. This is stirred up with water and again allowed to settle until all the grains of sand have subsided, when the turbid liquid is again decanted into M. This operation is continued until an examination of the sediment in B shows that all particles smaller than 0.05 mm. have been removed. The contents of this beaker B are then washed into a small porcelain dish and evaporated to dryness on the water bath. When dry, this sand may be gently ignited to burn off the organic matter, and when cool it is sifted through a series of sieves which will be described further on.

It is often convenient in separating the silt, fine silt, and clay from the sand to decant before the last portions of sand have settled. This hastens the operation of separating the fine and the coarse material, especially where there is a large mass of sand and but little fine material to be removed. In this case, the turbid liquid which is decanted is put into a separate beaker and the sand which has been poured off is recovered by a further decantation, and when free from all fine material it is added to the sand in the porcelain dish while the latter is evaporating to dryness. The turbid liquid in the beaker M is thoroughly stirred and allowed to settle until a drop taken from near the bottom of the beaker contains no solid particles larger than 0.01 mm., equal to two spaces of the eyepiece micrometer using the $\frac{1}{5}$-inch objective. The turbid liquid, containing only fine silt and clay in suspension, is then carefully decanted into another beaker, P. The sediment remaining in M is again stirred up with water and allowed to settle, and decanted as before. This operation is continued until all particles smaller than 0.01 mm. have been washed out of the sediment in the beaker. Care must be taken in pouring off the turbid liquid that none of the silt goes over, or if it does it must be recovered and added to that in beaker M at some later stage of the operation. The sediment remaining in beaker M should contain nothing larger than 0.05 nor smaller than 0.01 mm. if the separation has been carefully and completely made. This is washed into a platinum dish, evaporated to dryness on the water bath, ignited at a low red heat, cooled in a desiccator, and finally weighed.

The sediment in beaker P containing fine silt and clay is stirred up with water and allowed to settle until everything larger than 0.005 mm. has subsided, as determined by a microscopic examination as before. The turbid liquid, containing only "clay" or material finer than 0.005 mm., equal to one space of the micrometer, is then decanted into a larger beaker, C, of 1 or 2 liters capacity, and the sediment in P repeatedly washed until all of the clay has been removed. When this has been accomplished, the sediment is washed into a platinum dish, evaporated to dryness, ignited, and weighed.

The clay water usually amounts to a number of liters, and to prevent it accumulating to any great extent it is the practice in this Division to measure it in a liter flask and take 100 cc. from each liter to evaporate to dryness. The remainder of the clay solution is thrown away. When the liter flask is full to the mark with the clay solution, care must be taken to thoroughly mix it before taking out the tenth part to be evaporated to dryness. The successive 100 cc. of clay water are poured into a beaker and evaporated in a platinum dish as rapidly as possible. When this clay water has been evaporated to dryness, the sediment is ignited and weighed and the weight multiplied by ten to give the total amount of fine material in the original sample.

In the course of the analysis, several of these grades may be separated at once, to facilitate the operation, by the use of additional beakers. It is best to transfer material into smaller beakers as the quantity becomes less in being freed from the finer particles, as this materially hastens the time required for the material to subside.

The sand which was separated in the beginning of the operation and dried and ignited in the porcelain dish is sifted through a series of sieves of the following dimensions: Three round brass sieves 4 inches in diameter are used, which fit into each other and into a cup at the bottom. The top sieve has circular holes 2 mm. in diameter, the second has similar holes 1 mm. in diameter, and the third has holes 0.5 mm. in diameter. These grades are sifted in a very short time.

The material which passes through the lower sieve is then sifted through two grades of bolting cloth—No. 5 and No. 13—having square holes approximately 0.25 mm. and 0.1 mm. in linear dimensions. This sifting requires quite a long time, on account of the fineness of the spaces through which the particles have to pass. It can conveniently be done upon the shaker which is used for the disintegration of the original sample. The two pieces of bolting cloth can be fitted into conveniently arranged brass rings, and the samples should be shaken for an hour or two on this shaker.

Each of these grades of sand are weighed without previous drying, as the amount of hygroscopic moisture is usually inappreciable.

The operation of mechanical analysis is frequently made tedious and sometimes impossible by flocculation. If any tendency to this is discovered, vigorous stirring should be resorted to, and this can best be done with one of the improved forms of egg-beaters found in the market. A small trace of ammonia also assists in overcoming this tendency to flocculation, but it should be added very cautiously, as an excess of ammonia will cause many soils to flocculate. It is a practice in the laboratory of this Division to add 2 or 3 drops of strong ammonia to each sample just before it is put into the shaker. If the sediments are left standing for a length of time, flocculation is liable to occur, and it is very important that the work should be pushed along as rapidly as possible. The operator will find by experience that while waiting on one sediment to subside he may be decanting into extra beakers, which in time may be added to the proper beaker.

The water used in the mechanical analysis should be distilled, if possible, but clear river, well, or hydrant water may be used. In case distilled water is not available, the solid matter in suspension or in solution in the water used should be determined by evaporating 500 cc. of the water to dryness, and igniting and weighing the residue. Allowance should then be made for this residue in the clay determination.

Eight or ten samples can be started at once and can be pushed through about as readily as a single sample. It is not advisable, however, to attempt to carry on more than this number, because the proper attention can not be given to the beakers. A fresh set of samples may be started on the shaker, however, a day or two before the last set is finished. It requires from six to ten days to complete the analyses of a set of samples if close attention is given to the decantations.

INTERPRETATION OF THE RESULTS.

1. *The texture of soils.*—In the mechanical analysis of soils, it is the practice of this Division to separate the mineral matters into eight grades, according to the diameters of the grains. The number of grains and the diameters have been arbitrarily fixed with respect to the convenience of separation. It would be very desirable, of course, to increase the number of grades, but the practical difficulty of making the separations is so great that the results would not justify the extra time required for the work.

The notes and calculations on the analysis are entered in a book specially designed for this purpose and kept as an original record in the files of the Division. For convenience in referring to the analysis however, the results are copied upon a card upon which the following form is printed. These cards are filed away as in an ordinary card catalogue:

No.... Locality.. Vol.... Page....

Geol. formation.. Crop............

	Diameter (mm.).	Conventional names.		Per cent.	Remarks.
(1)	2—1	Fine gravel	=		
(2)	1—.5	Coarse sand	=		
(3)	.5—.25	Medium sand	=		
(4)	.25—.1	Fine sand	=		
(5)	.1—.05	Very fine sand	=		
(6)	.05—.01	Silt	=		
(7)	.01—.005	Fine silt	=		
(8)	.005—.0001	Clay	=		
	Total mineral matter		=		
(9)	Loss at 110° C.		=		
(10)	Loss on ignition		=		
	Total		=		

Analyist,

This gives the bare texture of the soil. In many cases, especially if the type of soil is well known, this is sufficient to indicate the relative relation of the soil to moisture as compared with the typical conditions in the area. With a majority of the soils of the Atlantic Coast States the amount of clay is a very sure indication of the relation of the soils to moisture and of the relative amount of moisture the soil will maintain. In the loess soils of the West the amount of silt so far predominates that it determines the relation of the soil to moisture. In the plains marl the amount of very fine sand, ranging from 60 to 75 per cent, determines the relation of the soil to water.

2. *The structure of soils.*—In examining soils from new localities, it is not sufficient to know the kind and size of the grains that form the framework of the soil, for the arrangement of these grains has a very important influence upon the relation of the soil to water. Two soils may have the same texture but maintain very different amounts of water if the grains have a different relative arrangement. One soil may be loamy while the other may be quite impervious to water. This is one of the most important properties of soils, but so far no satisfactory method has been devised for determining with any exactness the arrangement of the grains constituting the structure of the soil. The most promising method is based upon the flow of a fluid through a given volume of soil. Where the grains are evenly distributed in the soil and the spaces between the grains are of nearly uniform size, the resistance to the movement of air or water is at a maximum, while if the grains are unevenly distributed in the soil, as they are in loamy soil, some of the spaces being very much larger than others, the resistance to the movement of air or water is very much less. The method for determining these points has not yet been perfected, as it is very difficult to take a sample of the soil in its natural position in the field of a sufficient size to use for these investigations.

The following table will give an idea of the accuracy which may be expected in the use of this method for the mechanical analysis of soils:

Number.	Description and locality.	Analyst.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
			Per ct	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*
472	Truck soil from Marley, Md	A	0.14	0.41	0.61	6.66	39.95	32.94	2.73	8.24	2.65	2.71
		B	0.18	0.85	0.60	6.61	42.55	30.82	4.44	6.21	3.18	5.61
937	Limestone soil from Hagerstown, Md	A	4.15	9.86	0.00	0.09	0.56	1.29	1.88	10.23	3.95	68.15
		B	2.62	10.61	0.00	0.11	0.65	1.27	2.51	11.10	4.92	67.52
1803	Plains marl from Agallala, Nebr	A	1.05	3.31	0.00	0.00	0.00	0.99	71.62	13.42	1.43	8.84
		B	1.85	2.76	0.00	0.00	0.02	0.85	71.91	11.66	2.30	10.60
1317	Loess from Virginia City, Ill	A	0.83	4.78	0.00	0.16	0.15	0.18	17.50	65.99	2.13	7.74
		B	0.69	4.42	0.00	0.06	0.11	0.18	31.38	51.37	3.62	9.23
	Mixtures of the above samples.											
I	3 parts truck, 1 part limestone soil[1]	A	0.89	4.51	0.24	6.42	34.41	23.18	2.42	6.82	2.06	19.00
	Calculated[2]	A	1.12	2.76	0.45	5.00	30.08	25.11	2.53	8.73	2.96	19.04
	3 parts truck, 1 part limestone soil[1]	B	0.80	3.91	0.56	6.43	36.03	21.76	2.71	5.35	2.61	21.32
	Calculated[2]	B	0.78	3.28	0.45	4.97	32.05	23.41	3.95	7.42	3.60	21.07
II	2 parts truck, 1 part limestone soil[1]	A	1.30	3.40	0.29	4.42	27.77	25.76	3.34	8.10	2.29	22.67
	Calculated[2]	A	1.46	3.54	0.40	4.47	26.80	22.39	2.44	8.89	3.07	24.51

[1] Actual results of the analysis of the mixtures.

[2] Texture of the mixture calculated from the analyses of the separate samples.

Number.	Description and locality.	Analyst.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
	Mixtures of the above samples—Continued.		*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*	*Per ct*
II	2 parts truck, 1 part limestone soil[1]	B	1.33	3.68	0.27	5.26	30.13	21.78	3.05	6.44	2.89	26.91
	Calculated[2]		0.99	4.09	0.40	4.43	28.57	20.96	3.79	7.84	3.76	26.24
III	1 part truck, 1 part limestone soil[1]	A	1.92	3.76	0.32	4.02	22.45	17.10	2.91	9.34	2.32	34.70
	Calculated[2]		2.14	5.13	0.30	3.37	20.25	17.11	2.30	9.23	3.29	35.42
	1 part truck, 1 part limestone soil[1]	B	1.02	4.87	0.33	4.11	24.60	17.01	2.77	5.55	3.46	36.94
	Calculated[2]		1.40	5.72	0.30	3.35	21.59	16.04	3.47	8.65	4.05	36.56
IV	1 part truck, 2 parts limestone soil[1]	A	2.59	6.70	0.20	2.49	16.23	14.01	2.91	7.25	2.38	44.19
	Calculated[2]		2.74	6.69	0.20	2.28	13.67	11.84	2.15	9.56	3.50	46.32
	1 part truck, 2 parts limestone soil[1]	B	2.63	6.04	0.17	2.46	12.25	14.36	2.82	6.38	3.50	47.21
	Calculated[2]		1.80	7.34	0.20	2.26	14.60	11.11	3.14	9.47	4.34	46.87
V	1 part truck, 3 parts limestone soil[1]	A	2.89	6.54	0.16	1.90	12.14	10.77	3.38	7.74	2.47	49.49
	Calculated[2]		3.12	7.48	0.15	1.72	10.40	9.19	2.09	9.71	3.60	51.76
	1 part truck, 3 parts limestone soil[1]	B	2.89	6.81	0.11	2.80	12.25	13.45	2.78	6.30	4.35	50.12
	Calculated[2]		1.99	8.16	0.15	1.71	11.11	8.63	2.97	9.86	4.48	52.04
V	1 part plains marl, 1 part limestone soil[1]	A	3.11	6.76	0.03	0.09	0.34	1.01	33.05	15.15	2.73	35.85
	Calculated[2]		2.59	6.58	0.00	0.04	0.28	1.13	36.75	11.82	2.68	38.49
	1 part plains marl, 1 part limestone soil[1]	B	2.75	7.93	0.04	0.11	0.36	0.97	37.02	12.10	4.38	35.75
	Calculated[2]		2.23	6.68	0.00	0.05	0.33	1.05	37.20	11.38	3.61	39.06
VII	1 part loess, 1 part limestone soil[1]	A	2.17	4.81	0.00	0.10	0.40	0.75	19.06	32.12	2.61	38.77
	Calculated[2]		2.48	7.32	0.00	0.12	0.35	0.73	9.69	38.10	3.03	37.94
	1 part loess, 1 part limestone soil[1]	B	1.83	8.71	0.00	0.13	0.45	0.76	16.73	31.98	3.26	37.57
	Calculated[2]		1.65	7.51	0.00	0.08	0.37	0.72	16.94	31.23	4.27	38.37

[1] Actual results of the analysis of the mixtures.

[2] Texture of the mixture calculated from the analyses of the separate samples.

Four soils were analyzed by each of two men, A and B. These analyses are given in the first part of the table in such a way that the work of the two men can be directly compared. Then mixtures were made of these different samples and the mixtures analyzed by each of the two men. As a means of giving a double check upon the work, the composition of the mixture was calculated from the results each man obtained in his analyses of the separate samples. The first line of the mixture, therefore, gives the actual results obtained by the analyst, and the second line, distinguished as "Calculated," shows the results which should have been obtained based upon his analyses of the separate samples. This gives a check on the two men and on the work of each one. The samples were all given different numbers, so that neither of the men knew what he was working on. It will be seen that the results do not agree perfectly, but it is considered a very satisfactory piece of work with this method, and is about as accurate work as can be obtained by the use of this method in general laboratory work.

DETERMINATION OF MOISTURE IN ARABLE SOILS.

This Division has begun to keep systematic records of the moisture conditions in some of the principal soil areas of the United States adapted to some of the principal agricultural interests. Records have been undertaken of the moisture conditions in soils adapted to truck, to the different classes and types of tobacco, to wheat, grass, and other staple crops and interests, as well as in soils under different methods of cultivation, especially under irrigation and dry farming in the arid regions of the West.

HOW SAMPLES SHOULD BE TAKEN.

There is at present only one practicable method of determining the amount of moisture in the soil of the field, namely, by taking a sample of soil with a brass tube driven into the soil, withdrawing the sample and drying it completely in the laboratory and determining the loss in weight. As will be seen later, this is not thoroughly satisfactory. The soil-sampling tubes used by this Division are made out of brazed brass tubing about seven-eighths of an inch in internal diameter and 15 inches long. The tubing is No. 21, Stubbs's gauge. In one end a brass collar, about one-fourth of an inch wide, is sweated in. The end of the tube is then turned off in a lathe, giving a rather long taper but letting the point be the full thickness of the collar. A mark is cut into the tube 12 inches from this cutting edge. In the method as used by this Division, the sample is taken by driving the tube down into the soil until the mark on the side of the tube is level with the surface of the surrounding soil. Three inches of the tube is then left exposed with which to withdraw it. The tube should be driven in by quick light taps with a piece of wood, rather than with a piece of metal, to prevent battering the top. The tube is then to be turned in the hole and worked gently back and forth to break off the column of soil from the bottom, when the sample can be carefully withdrawn. Both ends of the tube are then to be immediately covered with rubber caps which fit tightly and prevent any loss of water while the sample is being transported to the laboratory. Rubber finger cots of an appropriate size are conveniently used for these caps, with a rubber "jack-stone ball" forced up snugly into the top of the cot to prevent the tube from cutting the rubber.

ERRORS LIABLE TO OCCUR IN TAKING SAMPLES.

This method of sampling is neither very convenient nor very accurate. In the first place, there is often a marked difference in the texture of a soil within the same field and within a radius of a few feet. This unevenness is often indicated by a difference of color or in the general appearance of the soil. Further, it is impossible to cultivate the soil and leave it in the same physical condition throughout. A man's footstep on a plowed field has been known to make such a difference in the physical condition of the soil as to be plainly apparent in the development of the crop throughout the season. In plowing or in cultivating or in hoeing, it is not possible to stir the soil and make it fall down in exactly the same way over every part of the field or even over every part of a small plat. The effect of roots also and worm-holes, as well as the occurrence of stones and large gravel, modify very materially the physical conditions of the soil in their immediate neighborhood.

The method of sampling itself is liable to errors which even the most careful manipulation will not entirely eliminate. When the brass tube is driven into the ground, there is always some friction on the inside of the tube which tends to compress the soil below the tube, so that the column of soil does not rise to a height inside corresponding to the level of the soil on the outside of the tube. It is to diminish this friction as much as possible that the collar is inserted in the end of the sampling tube so that the core of soil will be a little smaller than the tube. This only diminishes the source of error to a certain extent, and does not entirely eliminate it. The sample usually represents a less depth than it is intended to represent—that is, instead of taking a sample to a depth of 12 inches the sample may only represent in reality a depth of 8 or 9 inches. If the surface soil is drier than the subsoil, then the sample taken will contain less moisture than the average content of the soil to a depth of 12 inches. If the surface soil is wetter than the subsoil, then the sample taken will contain more moisture than the average water content to a depth of 12 inches. If the real depth represented by the sample in the tube varies from day to day on account of this source of error, then the water content of these soils will vary from day to day, or even in samples taken on the same day without any variation in the rainfall.

From these various causes, which can neither be foreseen nor entirely eliminated, it is no unusual thing for samples of soil taken side by side at the same time to vary as much as 3 or 5 per cent in water content.

TIME OF TAKING SAMPLES.

Samples should be taken as nearly as possible at the same time each day. To secure uniformity in the work of different observers, the samples should be taken at 6 o'clock in the evening, or as near that hour as possible, the exact time being stated on the shipping tag. If heavy rain threatens, it is better to take the samples a little early rather than during or after the rain.

DEPTH AT WHICH SAMPLES SHOULD BE TAKEN.

The depth at which the moisture samples should be taken depends somewhat upon the nature of the work. The usual depth is 0 to 12 inches. It is better, when possible, to divide this depth and take two samples at depths of 0 to 3 and 3 to 12 inches, although this nearly doubles the amount of work involved. Occasionally samples should be taken at less intervals of depth, such as 0 to 3, 3 to 6, 6 to 9, 9 to 12 inches, to give an idea of the distribution of the water in the soil.

Where samples are taken at different depths, the lower samples should be taken from the same hole as the shallower samples. The 0 to 3 inch sample may be taken, then the 3 to 6 inch sampling tube driven down into this same hole, and so on for successive depths. Care must be taken to prevent the surface soil from falling down into the hole between the successive samples.

FORM FOR DESCRIPTION OF SAMPLES.

After taking the sample and putting the rubber caps on the tube, it is to be put into a cloth sack and securely tied and a tag fastened to it. On the tag a form should be printed to be filled out immediately upon taking the sample. The name of sender and locality, and also the date and time of taking the sample, should be given, together with notes as to the character of season and conditions of soil. The following form has been adopted for use in this Division:

Name ....

Post-office .... State ....

Date .... 189.. Time .... o'clock .... M.

Kind of soil .... Rainfall .... inch..

Too dry.
Condition of soil: Favorable.
Too wet.
(Strike out words not meant.)

Remarks:

....

(Note each time this plat is cultivated, weeded, or irrigated, and state how done.)

....

....

When a number of samples are to be taken by the same observer each day, it is convenient to put them into sacks of different color, so as to attract attention and lessen the possibility of mixing the samples. The sacks can be conveniently dyed so as to have red, blue, and black, in addition to white sacks. These sacks should be used where samples are taken at different depths, or where samples are taken from different soils or different plats.

CULTIVATION AND CROPPING.

The conditions usually selected for the record of soil moisture are the following:

1. Virgin soil.
2. Grass sod.
3. Uncultivated land which has formerly been cultivated.
4. Cultivated after the method usually practiced in the locality.
    (*a*) Without crops growing on the land.
    (*b*) With crops growing on the land.

5. Subsoiled land.
    (*a*) Without crops growing on the land.
    (*b*) With crops growing on the land.
6. Irrigated fields, either with or without crops.

As no two crops develop in exactly the same way or require the same conditions of cultivation, there is an uncertain factor when plants are growing, which should usually be eliminated in comparative records. It is impossible to have uniformly similar conditions if the soils are cultivated, for they can not be cultivated in exactly the same way and at exactly the same time at different stations, on account of differences in climatic conditions. There is, therefore, an uncertain element when soils are cultivated, which should be eliminated to give the greatest comparative value to the moisture determinations. For these reasons this Division has adopted the practice of taking the moisture conditions in the uncultivated soil, kept free from weeds or growth of any kind, as the basis of comparison between soils of different kinds or in different localities.

It is desirable to know how different methods of cultivation and different crops change these soil conditions, and to this end duplicate determinations may be made in adjoining plats, where these modified conditions of treatment or of crops may be maintained at will.

LOCATION OF PLATS.

The plats from which daily samples are to be taken for the moisture records should be selected with great care and judgment to represent fairly well the type of a considerable area of land for which the records are to be kept. Locate the plats away from fences, trees, buildings, and rich garden spots, and where possible upon a level piece of ground. The plats should be at least 20 feet square, and substantial stakes should be driven at the corners to mark the boundaries of the plat. The soil samples should be taken from this plat during the entire season in a very methodical way. No samples should be taken closer than 3 feet to any side, and they should be taken farther from the side than this if there are deeply rooted plants growing just outside the plat.

In taking the samples, it is well to lay off an imaginary line at least 3 feet from the side of the plat. Take the first sample at one end of this line and, after withdrawing the tube, fill up the hole with loose soil and stick in a small peg to mark the spot. A piece of broom handle will answer well for this purpose. The sample for the next day should be taken about a foot away from the peg, on the line which has been established, and after filling up this hole the peg should be removed to mark the spot where the last sample was taken. In this way continue in a straight line across the plat, never getting nearer than 3 feet to any of the sides. After one row is finished, begin a second row a foot away from the first. With this methodical manner all danger of taking two samples from the same hole is avoided and the influences of the previous sampling upon the conditions of the soil are reduced to a minimum.

In taking samples, avoid walking on the part of the plat not sampled. If the plat is likely to be trampled upon, stretch stout cords or wires around the stakes at the corners. If the plat is to be cultivated with the rest of the field, the cords can be let down to permit of the cultivation. Unless crops are purposely grown upon the plat, the soil is to be kept free from weeds or vegetation of any kind. On the cultivated plat this may be done either by pulling the weeds or by cutting them off with a sharp hoe, stirring the ground as little as possible.

HOW THE PLATS SHOULD BE TREATED.

1. *Virgin soil.*—Lay off the plat as described above, leaving the natural vegetation and noting the character of the vegetation and the stage of growth at frequent intervals during the season.

2. *Grass sod.*—The grass should be allowed to grow as on the rest of the field, and cut at the proper time. If it is in a pasture, the stock should be allowed to graze on it as on the rest of the field, as the same conditions should be maintained on all parts of the field. The sample should be taken by pushing aside the grass or by pulling up a small tuft of grass. As little trash, stubble, grass, or roots should be taken in the sample as possible. Reports should be made at least weekly of the height of the grass, stage of growth, dates of cutting, or the condition of the pasture.

3. *Uncultivated land.*—This plat should be upon land which has recently been cultivated. In preparing for the work, the surface should be leveled off in as even and uniform a manner as possible. It should not be cultivated, however, during the season, except such cultivation as may be necessary to keep the surface free from weeds. In the preliminary report the length of time should be stated since the soil has been cultivated, as well as the character of cultivation and the kind of crop used at that time.

4. *Cultivated land.*—If the effect of cultivation alone upon the water content of the soils is to be studied, the plat should be cultivated in the same way and at the same time as the rest of the field, and in strict accordance with the prevailing practice of the locality. If the staple crop is grown on ridges or hills, throw up similar ridges or hills and cultivate as though plants were actually growing on the plat. Take the samples from the crest of the ridges, in the places the plants would occupy if a crop had been planted. The time and manner of cultivation should be noted.

5. *Subsoiled land.*—In studying the effect of subsoiling on the water content of soils, the same general directions should be followed as given under paragraph 4. The plat may or may not be subsequently cultivated, and it may or may not have plants growing upon it, according to the purpose of the investigation. The subsoiling should be done

in all cases a sufficient length of time before the observations begin so as to insure a soaking rain, which shall put the subsoiled land in good condition and compensate for the drying effect of the subsoiling.

6. *Irrigated land.*—The object of irrigation is to maintain, through the artificial application of water, uniform conditions of moisture, or conditions better adapted to the proper development of crops. The necessity for this is not confined to the soils of the arid regions, but wherever, through the vicissitudes of the season, the moisture supply in the soil falls below a certain minimum amount below which crops suffer water should, if practicable, be applied to the soil as a means of preventing serious damage to the crop.

The irrigated plat should be laid off as are the others, and the samples should be taken in the same way. In the method and the time of

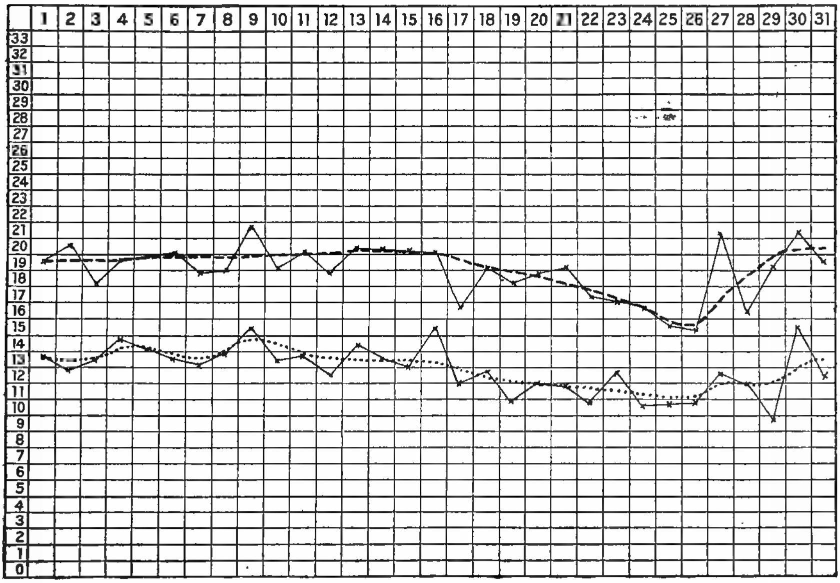


FIG. 1.—Curves showing the moisture content of two tobacco soils of the Connecticut Valley, July, 1895.

the application of water the local practice may be pursued, or any modification of this which suggests itself to the investigator as likely to be of some practical value. Weekly reports should be made of the time, mode, and extent to which the soil has been thus artificially supplied with water.

A diagram is given showing how the results of the daily moisture determinates are platted. The records are from two tobacco soils of the Connecticut Valley.

In the illustration the horizontal lines running across the page represent the per cent of water in the soil, ranging from 0 to 33 per cent, as indicated by the figures on the left-hand side. The vertical lines extending from top to bottom of the diagram mark off spaces corresponding to the days of the month. In platting the curve the per cent of water on each successive day is indicated by a small dot placed in the column corresponding to that day at a height corresponding to the per cent of moisture, as indicated by the figures on the left-hand side of the diagram. These points, representing the actual moisture determinations, are connected with a faint line, usually making a zigzag line across the chart, having somewhat the appearance of the edge of a cross-cut saw.

The meteorological conditions were very uniform over a considerable part of the month, so that much of the daily variations shown must be due to errors of determination. Some of the results are probably too high and others are too low. To eliminate these errors so far as possible, a heavy line is drawn across the chart midway between the observations, so as to occupy a mean position in respect to them. This line is usually a curved line, the curvature of which depends upon the occurrence of rain and the amount of evaporation. This line more truly represents the amount of water in the soil for any particular day or number of days than the actual results of the moisture determinations.

It is hoped that in a short while a more convenient and much more accurate method of determining the amount of moisture in the soil of a field will be so far perfected that it can be adopted by the Department. This is based upon the fact that a moist soil is a much better conductor of electricity than a dry soil. When this electrical method is perfected, it will be fully described and instructions prepared for the use of the instruments.

The soil appears to be a lifeless, inert material, but it is in reality full of life and movement. It is so extremely sensitive that any difference in the cultivation or cropping changes the physical properties of the soil and the relation of the soil to the rainfall. This gives a very important control of the water supply of plants through different methods of cultivation. It makes it necessary also that samples of soil for moisture determinations from different soils or from different parts of the country, to have any comparative value as records, be taken under as nearly as possible the same conditions of treatment.

METHOD OF DETERMINING THE AMOUNT OF MOISTURE IN THE SAMPLES.

When the samples are received in the laboratory, the information contained on the shipping tag is at once entered in an appropriate book. The rubber caps are then taken off and the soil pushed out and thoroughly and quickly mixed by hand upon a piece of oilcloth or manila wrapping paper. A suitable quantity is then put into an aluminum dish so that when loosely packed the dish is about full. The dishes used by this Division are 3 inches in diameter and three-fourths of an inch deep. They hold from 75 to 100 grams of soil, according to the way in which the soil is packed. It is convenient to have the aluminum dishes brought to the same weight by filing the heavier ones, so that the dishes do not need to be weighed for each determination. The weight of dish and fresh soil is taken as quickly as possible, and they are then put into a drying oven with a temperature regulator to keep the temperature uniformly 110° C. The samples are dried at this temperature for at least twenty hours, when they are again weighed and the loss of weight calculated in per cent of the original samples. The time required for the sample to attain a constant weight depends largely upon the nature of the soil and should be determined by preliminary trials at the start.

In publishing a table of the moisture determinations, it is better to take the figures from the curves which have been platted as already indicated, as this gives more truly the average daily amount of water in the soil than the actual determinations.

There are at least three ways of stating the results of the moisture determinations—in per cent of the moist soil, in per cent of the dry soil, and in parts per unit volume. The results will not appear to agree when calculated in these several ways, for there is no uniform basis of calculation except in the last case. When 100 grams of moist soil are dried until all the water is expelled, the loss in weight indicates the amount of water attached to the soil grains. This may be calculated in per cent of the original sample or may be expressed by comparing it with the weight of the dry soil. If the actual weight of water in 100 grams of moist soil was twice as great one time as another, the per cent of water would not be quite twice as great if figured on the fresh weight as with the smaller amount of water. If the water present is figured in per cent of the weight of dry soil, then, if there is twice as much water present in the soil one day as on another, the per cent of water will be twice as great. This method of expressing the results is rather better, therefore, where the fluctuations of the water of any particular field are to be studied, for twice the per cent always means twice the amount of water contained in the soil. This does not hold good, however, when different soils are compared, on account of the difference in weight of a unit volume of different soils. In other words, the same amount of rainfall does not give the same per cent of moisture in different soils by either method of calculation.

The following table illustrates this:

Soil.		First inch of rain.	Second inch of rain.	Third inch of rain.	Fourth inch of rain.	Fifth inch of rain.
Clay land:						
80 pounds per cubic foot	dry	6.5	13.0	19.5	26.0	32.5
	wet	6.1	11.5	16.3	20.6	24.5
Sand:						
100 pounds per cubic foot	dry	5.21	10.4	15.6	20.8	26.0
	wet	4.95	9.4	13.5	17.25	20.7

Assume that a clay land weighs 80 pounds per cubic foot, which is an average weight for a strong clay land, and that a sandy soil weighs

100 pounds per cubic foot. An equivalent of an inch in depth of rain is added to each of these cubic feet of soil. This will make 6.5 per cent of water in the clay land, calculated on the dry weight, and 5.2 per cent in the sandy land. If a second inch of water is added to these moist soils, there will be 13 per cent in the clay land and 10.4 per cent in the other. When the fifth inch of water has been added to the soils, there will be 35.5 per cent of water present, if figured on the dry weight, and this is just five times the percentage that was present when 1 inch had been added. If expressed in percentage of the moist soil, this would only be 24.5 per cent. This is considerably less than five times the percentage after the first inch had been added. Similarly, when the same quantity of water is added to the sandy soil, there will be 26 per cent and 20.7 per cent, respectively, if calculated on the dry or fresh weight of soil. On account of the difference in weight of the cubic feet of soil, 5 inches of rainfall will give 32.5 per cent if calculated on the dry weight of the clay soil, and 26 per cent in the sand. An equal percentage of water in different soils does not therefore necessarily mean an equal amount or weight of water in the soils. As more water is added, the difference continues to be more apparent, for with the increase in weight of the cubic foot of moist soil the successive amounts of water do not increase the percentage to the same extent.

It would be very much better if the amount of water could be expressed in unit volumes of the soil; that is, if the amount per cubic foot could be given. This would be strictly comparable, not only in the same soil but in all soils. The trouble is that the weight of a cubic foot of the soils would have to be determined for every individual case, and this is a difficult matter to determine, even under the most favorable circumstances.

It has been the practice in this Division to express the results of the moisture determination in per cent of the original sample; that is, to state that the soil on a certain day contained in its moist condition a certain percentage of water.

After the results have been calculated, it is advisable to plat them, as already explained, for the graphic representation of the variations which have occurred. It is very advisable also in publishing the results to take the data from this chart rather than to use the original figures, because this averages the results and eliminates or diminishes many of the errors of determination.

BULLETIN No. 5. A. S. 7.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF AGRICULTURAL SOILS.

TEXTURE

OF

SOME IMPORTANT SOIL FORMATIONS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1896.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF AGRICULTURAL SOILS,
Washington, D. C., February 14, 1896.

SIR: I have the honor to transmit herewith a number of photographs illustrating in a graphic way the texture of some important types of soil, with a brief descriptive text. The relation of soils to crops and the cause of the local distribution of crops have long been sought in the study of the chemical composition of soils and plants. Much of this work has at present no practical value, as other important influences have been overlooked, or at least have not been properly appreciated. The physical properties of soils have been recognized as important factors in crop production, but this side of the problem has never been sufficiently investigated to determine the nature or extent of the influence of these physical conditions. There have been no means of expressing the conditions in the physical properties of soils which practical farmers recognize in selecting crops and methods of cultivation.

The investigations of this division on the physical properties of soils throw an important light upon the relation of soils to crops and upon the local distribution of crops. It is not claimed that these are the only factors determining the relation of soils to crops, as might appear from the absence of any reference to the chemical composition of the soils, but it is believed that these investigations show that the physical conditions in many of these great soil areas have such a predominating influence upon the life and development of plants as to cause the differences in the chemical composition of the soils to be entirely lost sight of. The physical conditions maintained by these soils, therefore, determine the class of crops adapted to the land.

Our knowledge of the physical properties of soils is so far behind our knowledge of their chemical composition that the former needs to be advanced and pressed upon the attention of practical and scientific minds until the full importance of it is recognized.

I recommend that this report be published as a bulletin of this division.

Respectfully,

MILTON WHITNEY,
Chief of Division.

HON. J. STERLING MORTON,
Secretary of Agriculture.

TABLE OF CONTENTS.

LIST OF ILLUSTRATIONS.

TEXTURE OF SOME IMPORTANT TYPES OF SOIL.

RELATION OF SOILS TO CROP PRODUCTION.

The relation of soils to crops has been a fruitful source of investigation in the field and laboratory, especially during the past fifty years. Farmers are greatly concerned with this problem, for with the growth of cities in our modern civilization the class of nonproducers has been enormously increased; advances in industrial and commercial lines call for new crops or variations in those already grown; the great improvement in transportation facilities has largely extended the markets for all crops and farm products, at the same time increasing competition. It is thus of vast importance for the farmer to understand what crops are suited to different soils and what methods and processes will increase the yield and improve the quality of crops in the most economical way.

Plants require food to sustain life and promote growth. The chemical relation of soils to crops has been the main subject of investigation in the past, in the belief that this is the controlling factor in crop production. The relation of soils to crops depends also in part, however, upon the structure, physical properties, and conditions of the soil.

While the chemical and the physical properties of soils are each necessary factors in plant growth, one or the other may, in any particular case, exert such a controlling influence as to determine the relation of that particular soil to crop production and make the other relatively unimportant. Many of the results obtained from the chemical analyses of soils and plants have had as yet no interpretation which would give them a practical value, because the physical conditions of the soils are often the controlling factor in crop production, and these have not been sufficiently considered. It has been shown (Weather Bureau Bulletin No. 4) that the physical properties of the principal soils of the Atlantic Coast States have a controlling influence upon crop distribution and production. Soils adapted to the same class of crops under given climatic conditions have, as a rule, the same texture, or the same relative amount of sand, silt, and clay, and maintain the same physical conditions, while the texture and physical conditions of soils adapted to other classes of crops differ greatly from these.

The most important physical property of soils in their relation to crop production is, undoubtedly, the amount of water maintained by them. This is dependent mainly upon the resistance offered by the soil to the descent of rain.

The earth has three envelopes—an envelope of air, an envelope of soil, and an envelope of water. The envelope of air offers but little resistance to the descent of rain, as the rain encounters but little friction in falling through it, and it may pour down in torrential storms. The envelope of soil offers much more resistance to the descent of rain, and the rain, although it continues to fall through the soil until it finally reaches the level of the ocean, moves slowly by reason of the friction it encounters in passing through the minute spaces between the grains through which it has to move. On account of this resistance to the descent of rain and the slow rate at which it passes through the soil, the water is held back and retained for the use of plants. The resistance, and therefore the relative amount of moisture maintained by different soils, depends upon the volume of space in the soils for the water to enter; upon the texture, or how much the space is divided up, which depends upon the number of grains of sand, silt, and clay; upon how these grains are arranged; upon the amount of organic matter in the soil, and upon the depth of the soil.

As a rule, soils contain about 50 per cent by volume of empty space; that is, in 1 cubic foot of soil there is usually about one-half a cubic foot of space into which water or air can enter.

In a sandy soil this space is not divided up so much as in a clay soil, the grains of sand being larger the spaces between the grains are also larger, there is less friction, and the water moves downward more quickly. These sandy soils will not, therefore, maintain much moisture for the use of plants. The granules of clay soils, on the other hand, are so exceedingly minute, and there are such a vast number of them in a given weight of soil, that the spaces between them are exceedingly small, and consequently great resistance is offered to the descent of rain. The water moves very slowly, and a relatively large amount is maintained for plants.

Where the grains are evenly distributed in the soil and the spaces between the grains through which the water moves are of nearly uniform size, the resistance is at a maximum and the water moves very slowly through the soil. This is the condition of a soil which is puddled and which is close and impervious to water. If, on the contrary, the soil grains are grouped in masses and the grains of clay cling closely together, leaving some of the spaces larger and others smaller than when the grains are uniformly distributed, there will be less friction; the soil will be loamy and will maintain much less moisture than before, as the rainfall can move downward much faster by reason of the less amount of friction.

The accompanying illustrations show something of the importance of the arrangement of the soil grains. Pl. 1, fig. 1, shows a number of grains of silt spread out on a microscope slide and greatly magnified. These grains are immersed in water, and if they are agitated they move freely. There is no apparent attraction between grains, and if two of

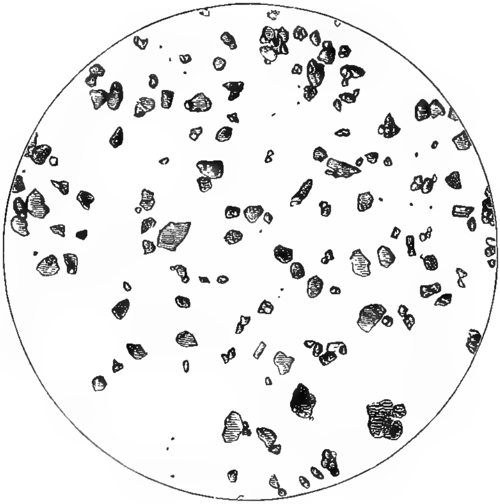


Fig. 1.

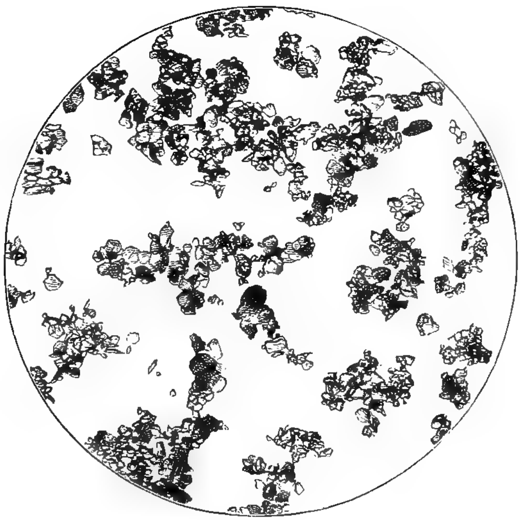


Fig. 2.

them collide they move apart as though there were a force acting between them to keep them at a certain distance from each other.

Fig. 2 shows the same grains of silt, to which a drop of limewater has been added. It will be seen that this has changed the entire arrangement of the soil grains. They are no longer spread out evenly over the plate, but have come together into groups—the grains have flocculated. In this condition the spaces between the grains are very uneven. The spaces between the grains which are clinging together are extremely small, while the spaces between the floccules, or masses, are relatively very large. This illustration may be applied to the soil itself, although all the spaces there are relatively very much smaller, as the grains are all much closer together.

Fig. 1 illustrates the condition of the grains in a soil which is puddled. All of the grains are uniformly distributed in the soil, and the spaces between the grains are nearly of uniform size. Fig. 2 illustrates the arrangement of the grains in a loamy soil where the spaces are of uneven size and the soil is quite pervious to water.

While the resistance or the friction in the soil determines the proportion of the rainfall retained for the use of plants, there exists in the soil, in addition, the force of surface tension or capillarity, which is able to move water from place to place in the soil and deliver it automatically to the roots of plants as it is needed. This force and the effect of different fertilizers in increasing or diminishing it have been described in Bulletin No. 4 of the Weather Bureau, and need not form a part of this paper. The forces which control the arrangement of the soil grains have also been described in the same bulletin, and need not be further considered here.

By properly controlling the temperature and water supply of a greenhouse, a florist may have plants mature at any season of the year. In accomplishing this result, different classes of plants require different treatment. Some require much more water than others. This is also true of certain kinds of development. If it is desired to force plants to mature early or to produce plants of fine texture, the soil is kept moderately dry; if a large leafy growth or late development is desired, the soil is kept more moist. In nature and in extensive field culture these conditions, it is true, can rarely be controlled, as we have about the same amount of rainfall over adjacent fields, but the soils when different in texture maintain quite as different conditions of moisture as those supplied to different classes of crops in greenhouse culture, and the conditions in each soil are found best adapted to a particular kind of crop.

Truck, wheat, and grass crops illustrate in a marked degree the effect of the texture and physical properties of soils on crop distribution and production.

TEXTURE OF SOME TYPICAL SOILS OF THE ATLANTIC COAST STATES.

The trucking interests of the Atlantic Coast States are confined to light, sandy soils; wheat is most successfully grown on a heavy loam, while the finest type of grass land is a strong, stiff clay.

The light, sandy truck soils are so open and porous that the water readily descends through them after a rain. The heavy limestone soils, on the other hand, are so close in texture and so retentive of moisture that the rainfall passes down through them very slowly and they maintain an abundant and uniform supply of water. The soils of the Atlantic Coast States, when arranged according to the amount of clay they contain, are nearly in the order of their relative agricultural value, as the amount of clay largely determines the relation of these soils to water. This is not universally the case, however, even in these States, as the grains of soil may be so arranged that the soil does not maintain the normal conditions of moisture.

As a rule, stiff clay grass soils, when in favorable condition for crops, contain from 18 to 22 per cent of water, or about 400 tons of water per acre, within 1 foot of the surface. Light, sandy truck soils, on the other hand, offering but little resistance to the descent of rain, maintain only about 5 or 6 per cent of moisture, or about 100 tons of water per acre.

The conditions in the truck soils are not favorable to wheat, for under the dry conditions prevailing in these soils the plant does not tiller well, but throws up one or two stalks which obtain but small size before the seed-head develops and the plant ripens. The conditions are not favorable for the development of a sufficient amount of foliage to gather plant food from the soil and atmosphere for a large crop. The conditions in the truck soils are still less favorable for pasture grasses, because these should not mature. If these truck soils were systematically irrigated and the crops grown on them artificially supplied with more water than the soils themselves can maintain under existing climatic conditions, good crops of grass or wheat could be produced. The very conditions which make them unfit for grass and wheat give them, however, their peculiar value for forcing vegetables to an early maturity. The early truck interests of the Atlantic Coast appear to be confined to soils containing not over 10 or 12 per cent of clay in the subsoil.

On very strong clay soils wheat is liable to make an excessive growth of straw and a relatively small yield of grain in proportion to the

2

UNITED STATES DEPARTMENT OF AGRICULTURE,

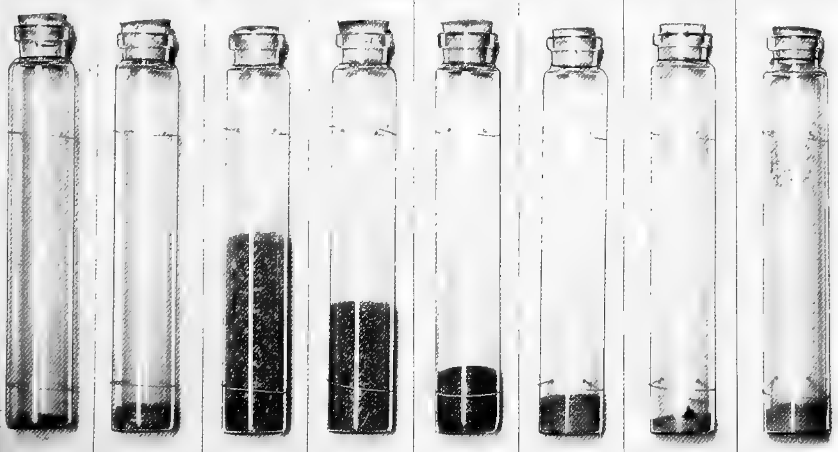
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL TRUCK LAND OF THE COLUMBIA FORMATION AT MARLEY, MARYLAND.

No. 472.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand*	*Silt*	*Fine silt*	*Clay*
0.49	4.96	40.19	27.59	12.10	7.74	2.23	4.40



2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm.	.05-.01 mm.	.01-.005 mm.	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

3

Wheat

UNITED STATES DEPARTMENT OF AGRICULTURE,

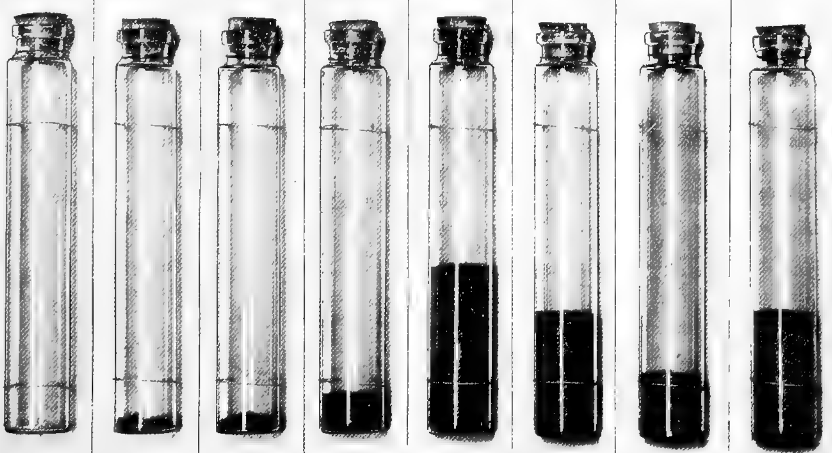
DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL WHEAT LAND OF THE CHESAPEAKE FORMATION AT DAVIDSONVILLE, MARYLAND.

No. 141.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	Coarse sand	Medium sand.	Fine sand.	Very fine sand	Silt	Fine silt	Clay
0.00	0.23	1.71	6 08	30.82	20.92	11.21	23.78



2-1 mm	1-.5 mm	.5-.25 mm	.25-.1 mm	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.

4

Grass.

UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL GRASS LAND OF THE TRENTON LIMESTONE FORMATION AT HAGERSTOWN, MARYLAND.

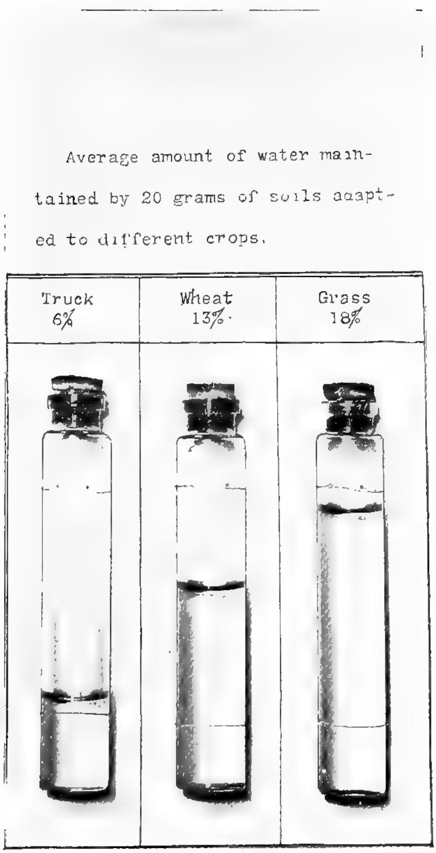
No. 937.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	Coarse sand	Medium sand	Fine sand	Very fine sand.	Silt	Fine silt	Clay
0.00	0.08	0.13	0.53	10.94	19.02	4.67	51.75

2-1 mm	1-.5 mm.	.5-.25 mm	.25-.1 mm.	.1-.05 mm	.05-.01 mm.	.01-.005 mm	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.


Average amount of water main-
tained by 20 grams of soils adapt-
ed to different crops.
Truck 6%
Wheat 13%
Grass 18%

amount of straw; it is apt to lodge and is liable to diseases. The best wheat lands contain from 20 to 30 or 35 per cent of clay and maintain about 12 or 15 per cent of water.

Pasture grasses require a long period of growth under relatively uniform conditions of moisture and temperature. Grass lands, while very retentive of moisture, should be well drained, so as to give free access of air to the roots of plants. A grass soil should contain sufficient clay to offer a great resistance to the descent of the rain, or the soil grains should be so arranged as to offer the necessary resistance. The best grass lands contain from 30 to 50 per cent of clay and maintain from 18 to 22 per cent of water.

Four illustrations are given, depicting graphically the texture of these three types of soils of the Atlantic Coast and the relative amount of water they maintain. For this purpose the separations of the different grades of material were put into small bottles and arranged on cards and photographed. The amount of water contained, on an average, in the upper foot of these soils was determined in samples taken each day in a small brass tube driven down to a depth of 12 inches.

The mechanical separation of the different grades of sand, silt, and clay, upon which the investigations of the texture and physical properties of soils are based, is made by sifting the larger grains through brass sieves and fine grades of bolting cloth, while the finer particles of soil (silt, fine silt, and clay) are separated by subsidence in water.

The types of soil presented in this bulletin are based upon an examination of samples from a great many widely separated localities. It is possible, of course, that as the work is extended and more detailed data becomes available these types will be considerably modified; but this is not probable, as most of them have been established on the basis of quite an extended examination of the several soil areas.

POTOMAC CLAY BARRENS.

It has been stated that the relation of the typical soil formations of the Atlantic Coast States to moisture depends partly upon their texture, or the relative amount of sand, silt, and clay they contain, and partly upon the arrangement of the soil grains, or the structure of the soil. The accompanying illustration of the subsoil of the Potomac formation of Maryland is a striking example of the influence of the arrangement of the soil grains upon the relation of the soil to water and to crops.

It will be seen from the mechanical analysis that this clay has about the same texture as the limestone soil, No. 937, which is considered the strongest type of grass land in the State. These Potomac clays, however, form remarkably barren clay hills, which are hardly adapted to any of our agricultural crops. It is a peculiar fact that the vegetation of these clay hills is much the same in character as that on the light, sandy soils of the pine barrens in southern Maryland, the natural tree growth consisting principally of pines and scrub oaks.

The grains of clay are so arranged that the soil has the effect of being puddled. In fact, this clay is used very effectively for stopping leaks in pipes and in puddling trenches or ditches. The material is so close and water moves through it with such extreme slowness that the rain does not enter it very readily. Plants likewise quickly use up the supply of water immediately around their roots and then suffer for an adequate supply, even though the soil around them may still be quite moist, because the movement of the water up to their roots is so extremely slow.

If these clay lands are properly treated, they can be made more loamy and more pervious to water through the rearrangement of the grains, and the whole relation of the soil to water be distinctly modified. With this improvement the soils are as productive as the limestone soils, but it is of course a matter of considerable expense and requires great care and judgment to improve them. The barrenness of these soils is not on account of any lack of plant food, but on account of the peculiar structure of the soil, or the arrangement of the soil grains, which increases enormously the resistance in the soil to the movement of water.

6

UNITED STATES DEPARTMENT OF AGRICULTURE,

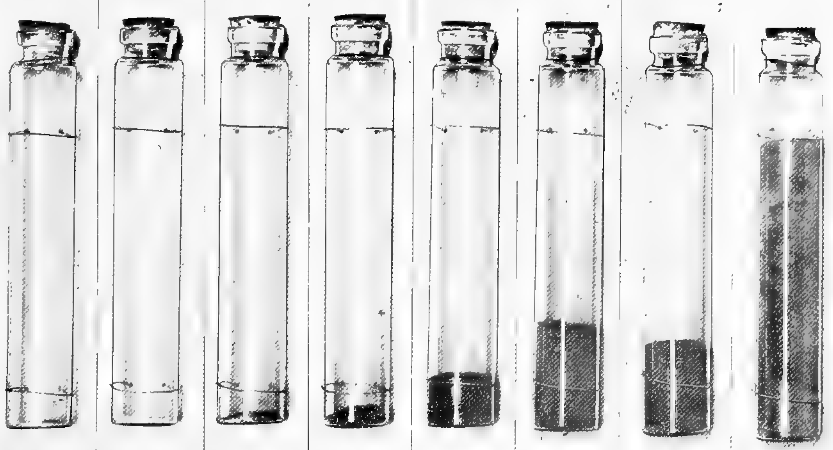
DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL CLAY LAND OF THE POTOMAC FORMATION NEAR BALTIMORE, MARYLAND.

No. 303.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand*	*Silt*	*Fine silt*	*Clay*
0.00	0.00	0.29	1.27	8.93	20.16	16 72	50.02



2-1 mm	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.

7

UNITED STATES DEPARTMENT OF AGRICULTURE,

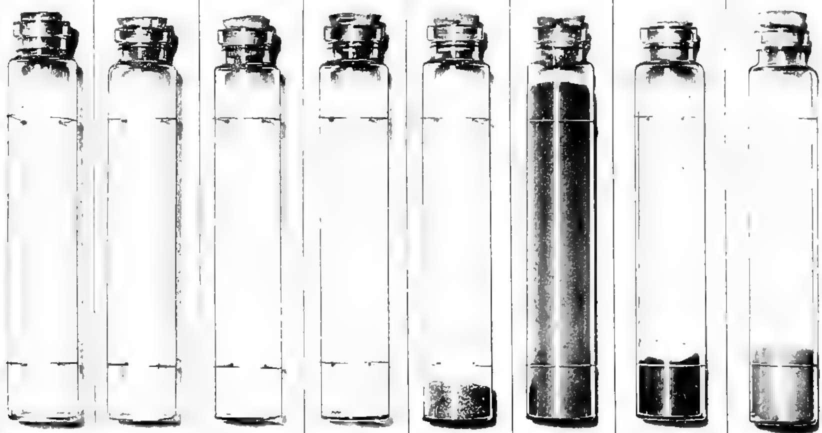
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL SUBSOIL OF THE UPLAND LOESS FORMATION NEAR VIRGINIA, ILLINOIS.

No. 1317.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	*Coarse sand.*	*Medium sand*	*Fine sand*	*Very fine sand.*	*Silt.*	*Fine silt.*	*Clay.*
0.00	0.00	0.00	0.01	7.68	61.85	9.60	15.15



2-1	1-.5	.5-.25	.25-.1	.1-.05	.05-.01	.01-.005	.005-.0001

DIAMETER OF THE GRAINS IN MILLIMETERS.

8

UNITED STATES DEPARTMENT OF AGRICULTURE,

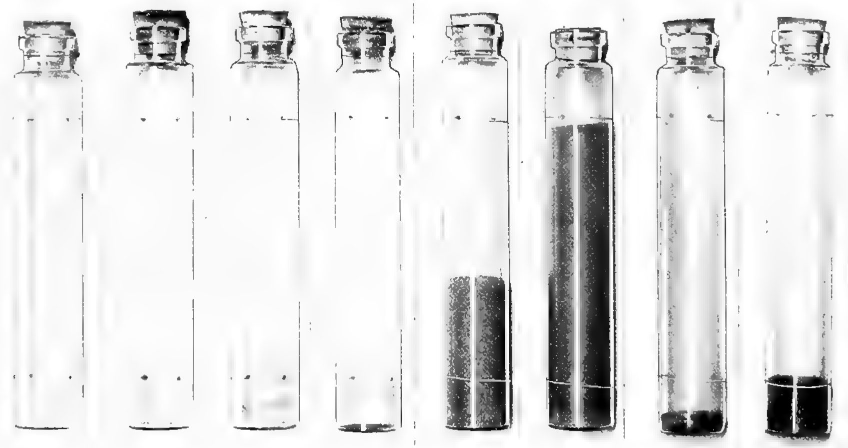
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL SUBSOIL OF THE LOESS FORMATION IN NEMAHA COUNTY, NEBRASKA.

No. 1715.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Fine silt	Clay
0.00	0.00	0.00	0.10	25.83	54.47	2.53	9.49



[illegible]	[illegible]	5-.25	.25-.1	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.

UNITED STATES DEPARTMENT OF AGRICULTURE,

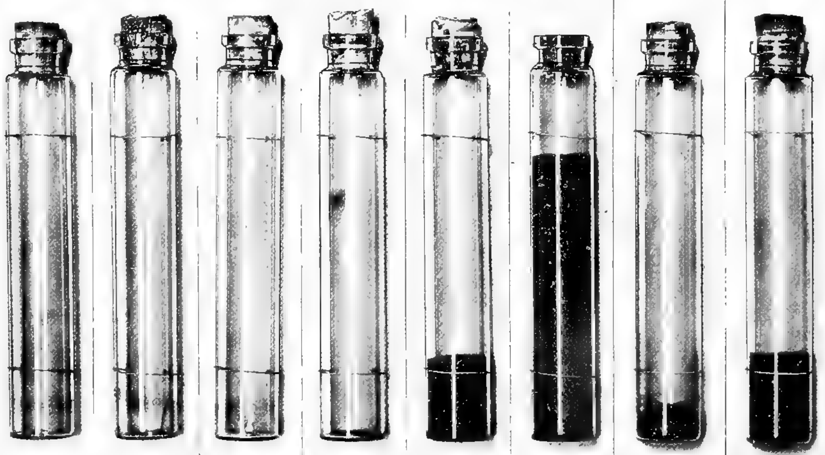
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL SUBSOIL OF THE LOESS FORMATION AT GENEVA, NEBRASKA.

No. 1671.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	*Coarse sand*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt.*	*Fine silt.*	*Clay.*
0.00	0.00	0.00	0.35	14.62	52.87	4.76	15.45



2-1 mm	1-.5 mm.	.5-.25 mm.	.25-.1 mm	.1-.05 mm.	.05-.01 mm.	.01-.005 mm	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

TEXTURE OF SOME TYPICAL SOILS FROM THE WEST.

LOESS.

It has been stated that the relation of the soils of the Atlantic Coast States to water and the water supply of plants is dependent mainly upon the amount of clay and upon the arrangement of the soil grains. These may be considered one great family or group of soils, in which there are quite a number of types adapted to different agricultural interests. In the West there are two other types or groups of soils, in which there are likewise subtypes.

Three illustrations are given showing the texture of the loess, which covers great areas in the West. A large number of samples of loess have been examined from different localities, particularly from Illinois and Nebraska, and typical samples of these are shown in the illustrations, including both the river loess and the upland loess of Illinois. The characteristic feature of the loess soils is the very large percentage of silt they contain, ranging usually from 50 to 70 per cent. These soils contain comparatively little clay, very much less clay than soils of equal agricultural value in the Atlantic Coast States. A soil containing 10 per cent of clay in one of the Eastern States would, as a rule, have no more than 10 or 15 per cent of silt, and such soils generally are too light in texture for wheat, but the loess soil, containing 10 per cent of clay and 50 or 60 per cent of silt, makes very good wheat land. The agricultural value of the soils of the Atlantic Coast States depends mainly upon the amount of clay they contain and the arrangement of the grains, but in these loess soils the agricultural value seems to depend upon the amount of silt they contain, while the amount of clay present appears to be relatively unimportant.

Loess, a very fine loam, and very homogeneous in structure. Cent. Dict.

PLAINS MARL.

Agents of the Department have collected a large number of samples of the "plains marl," which covers an extensive area in western Kansas and Nebraska and in eastern Colorado. Samples have been examined from about twenty localities in this area, and the soils appear quite uniform in texture. Two illustrations are given, showing the texture of the typical plains marl in Kansas and Nebraska.

This formation is characterized by containing a very large percentage of very fine sand, material one grade coarser in our scale than the loess which adjoins it.

This formation constitutes another great family or group. These soils make very fair wheat lands. They have the appearance and they feel like soils in the East containing from 20 to 30 per cent of clay. The amount of silt and clay in the plains marl is relatively small and appears to be unimportant, as the agricultural value seems to depend upon the amount of very fine sand. This ranges from 50 to 75 per cent in the samples which have been examined, and so far as can be determined the agricultural value appears to increase with the amount of this material.

UNITED STATES DEPARTMENT OF AGRICULTURE.

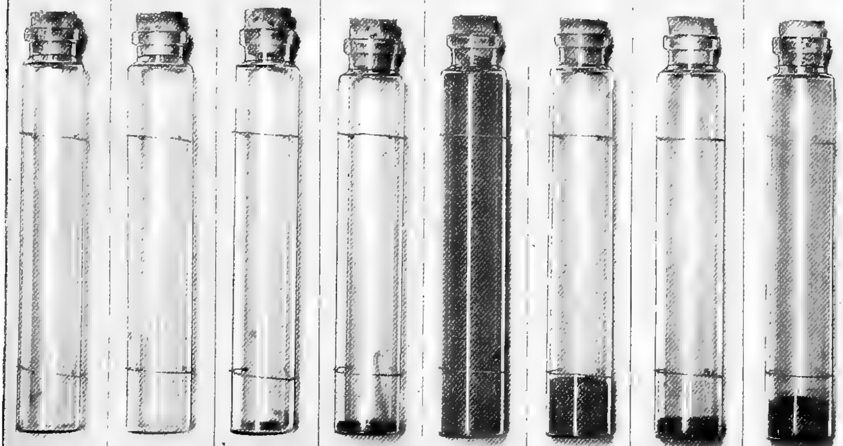
DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL SUBSOIL OF THE PLAINS MARL FORMATION IN CHEYENNE COUNTY, KANSAS.

No. 1789.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	Coarse sand	Medium sand	Fine sand	Very fine sand.	Silt.	Fine silt	Clay.
0.00	0.00	0.01	0.10	71.81	11.61	2.60	8.43



2-1 mm.	1-.5 mm	.5-.25 mm.	.25-.1 mm	.1-.05 mm	.05-.01 mm.	.01-.005 mm.	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

11

UNITED STATES DEPARTMENT OF AGRICULTURE.

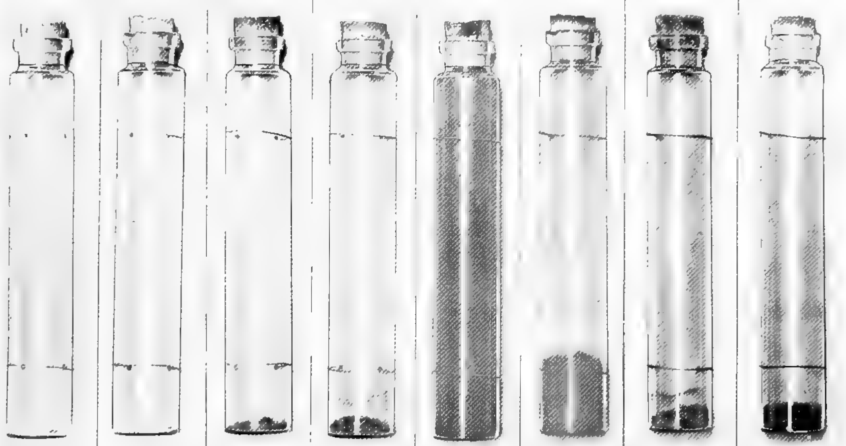
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL SUBSOIL OF THE PLAINS MARL FORMATION AT OGALLALA, NEBRASKA.

No. 1803.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt	Fine silt	Clay
[illegible]	0.00	0.03	1.95	75.58	12.93	1.31	4.22



2-1 mm	1-.5 mm	5-.25 mm	.25-.1 mm	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.

TEXTURE OF THE EARLY TRUCK LANDS OF THE ATLANTIC COAST.

The production of vegetables and small fruits for the early markets has developed into a very important and profitable industry along the Atlantic Coast from Florida to Massachusetts. The truck crops are grown upon light, sandy lands, which contain from 1 to 12 per cent of clay, the bulk of the material consisting of moderately coarse grains of sand. The light, open texture keeps these soils quite dry. The moisture content rarely exceeds 10 or 12 per cent, and on the average is about 5 or 6 per cent, while strong grass soils under the same conditions would maintain 18 or 20 per cent of water. These dry conditions enable the crops to be planted very early in the spring and force them to an early maturity. Other things being equal, the less clay the subsoil contains the earlier crops will mature. Soils containing from 1 to 6 per cent of clay are best adapted to Irish potatoes, sweet potatoes, asparagus, melons, pease, and tomatoes, and in general those crops which are usually planted in the spring. These soils are too light in texture for cabbage, spinach, and small fruits, because these fall-planted crops can not stand the winter well on such light lands. Such crops are better adapted to the heavier truck lands, containing from 6 to 12 per cent of clay, for the crops can stand the winters very well and thus have an advantage in the longer growing period over crops which are planted in the spring on the lighter truck soils. Irish potatoes will mature at least ten days or two weeks later on a soil containing from 8 to 10 per cent of clay than on a soil containing from 2 to 6 per cent, while fall-planted crops, such as cabbage, spinach, and small fruits, will mature quite as early on the heavier truck soils, and will produce a larger yield per acre and a better crop in texture.

Proximity to large bodies of water has a marked effect upon the time of maturity of truck crops, as it insures the crop against injury from late spring frost and enables one to plant at least two weeks earlier than would otherwise be safe. A soil situated immediately adjacent to the water, or on a point of land surrounded on two or three sides by water, matures crops fully ten days or two weeks earlier than similar soils situated half a mile inland.

On account of this protection against frost and the early maturity of the crops, as well as the advantages of cheap water transportation, lands situated immediately adjacent to the water have, as a rule, a much higher value for truck farming than inland soils of the same character.

The accompanying illustrations show the texture of the very early truck soils and the heavier truck lands from a number of typical localities along the Atlantic Coast. It will be noticed that these samples, taken from widely different localities, are very uniform in texture and form a distinct type of soil. In each of these localities soils containing from 1 to 6 per cent of clay are classed as the earliest truck soils, while those containing over 6 per cent are considered heavier, and are frequently designated as "cabbage land."

12

UNITED STATES DEPARTMENT OF AGRICULTURE,

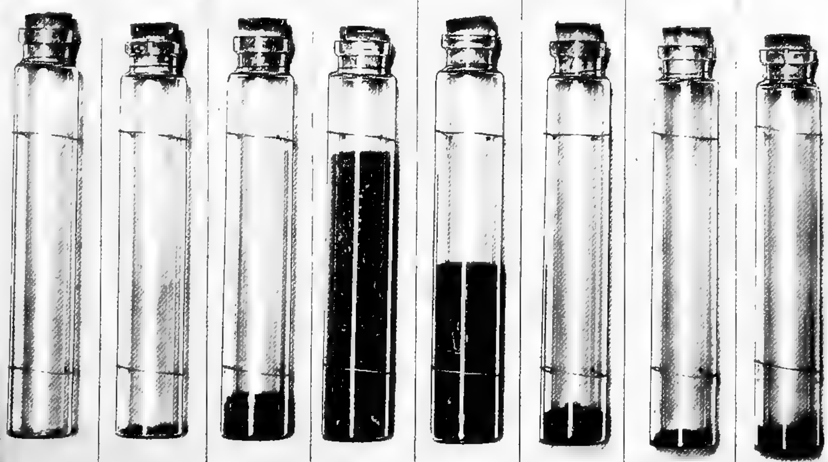
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL TRUCK LAND OF THE COLUMBIA FORMATION AT NEWBERNE, NORTH CAROLINA.

No. 1510.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	*Coarse sand.*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt.*	*Fine silt*	*Clay*
0.00	0.30	6.04	49.63	32.39	6.24	1.93	2.80



2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm.	.05-.01 mm.	.01-.005 mm.	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

13

UNITED STATES DEPARTMENT OF AGRICULTURE,

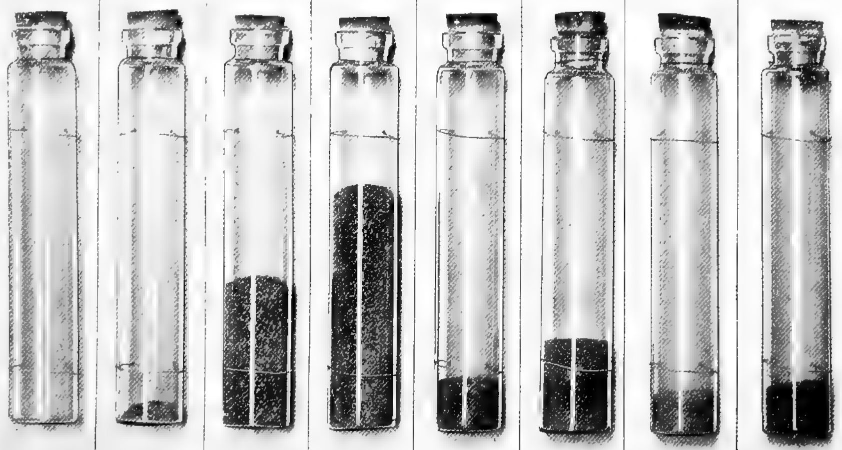
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL TRUCK LAND OF THE COLUMBIA FORMATION AT NORFOLK, VIRGINIA.

No. 1595.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand*	*Silt*	*Fine silt*	*Clay*
0.00	1.42	23.27	38.25	7.51	15.14	5.90	7.15



2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm.	.05-.01 mm.	.01-.005 mm.	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

14

UNITED STATES DEPARTMENT OF AGRICULTURE,

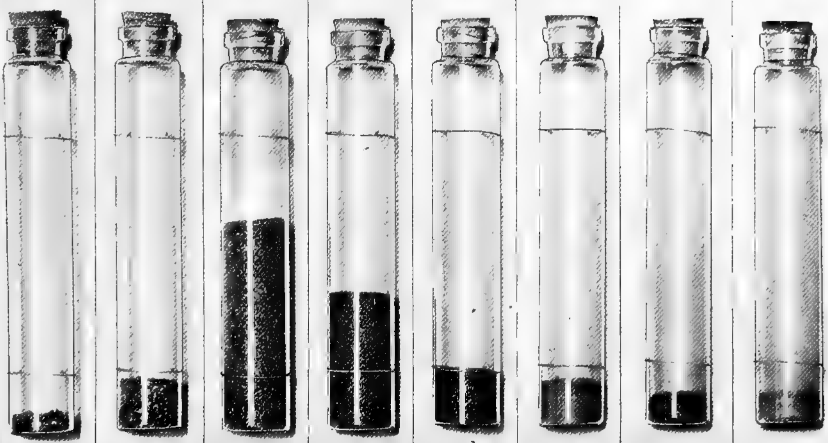
DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL TRUCK LAND OF THE COLUMBIA FORMATION AT SALISBURY, MARYLAND.

No. 1207.

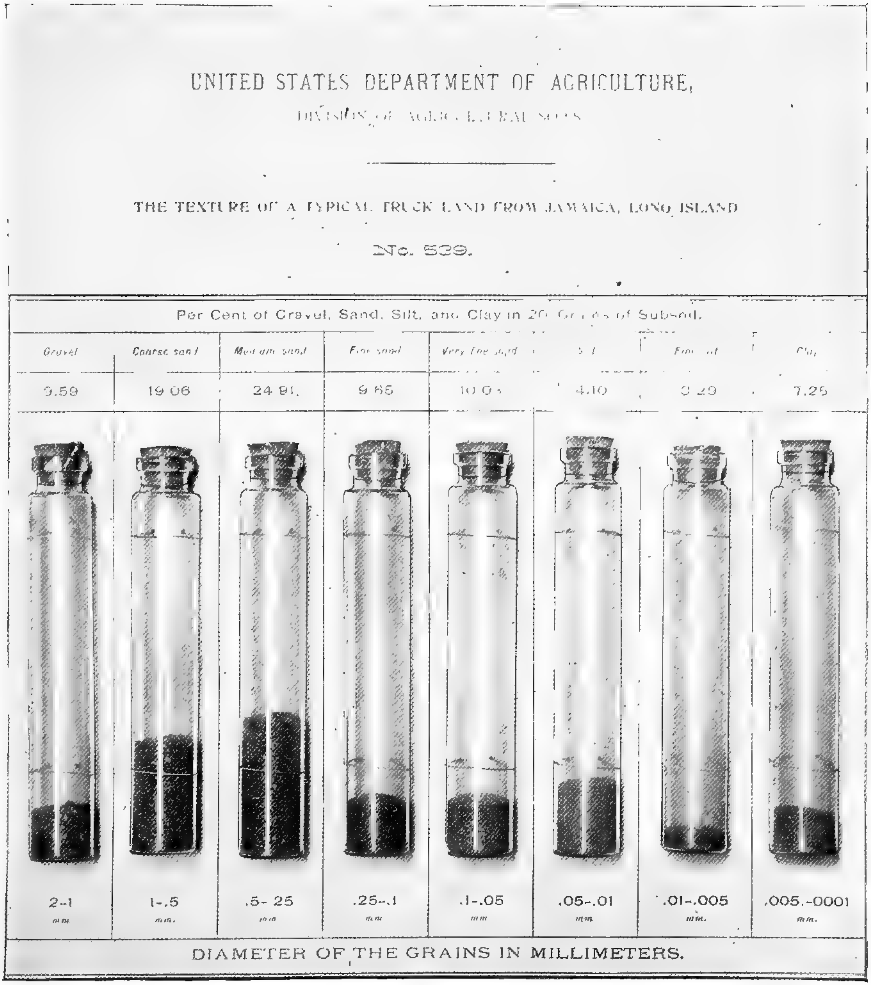
Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand.*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt*	*Fine silt*	*Clay.*
2.03	7.93	38.36	25.55	9.77	7.40	3.33	4.02



2-1 *mm*	1-.5 *mm.*	.5-.25 *mm.*	.25-.1 *mm.*	.1-.05 *mm*	.05-.01 *mm.*	.01-.005 *mm.*	.005-.0001 *mm.*

DIAMETER OF THE GRAINS IN MILLIMETERS.


UNITED STATES DEPARTMENT OF AGRICULTURE,
THE TEXTURE OF A TYPICAL TRUCK LAND FROM JAMAICA, LONG ISLAND
No. 539.
Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.
Coarse sand
9.59
19.06
24.91
9.65
4.10
7.25
2-1
1-.5
.5-.25
.25-.1
.1-.05
.05-.01
.01-.005
.005-.0001
DIAMETER OF THE GRAINS IN MILLIMETERS.

16.

UNITED STATES DEPARTMENT OF AGRICULTURE,

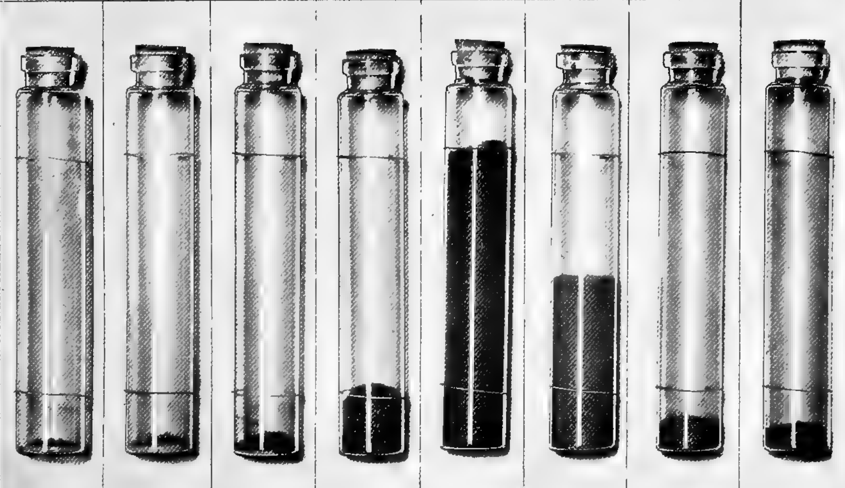
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL TOBACCO LAND AT EAST HARTFORD, CONNECTICUT.

No. 729.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand.*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt.*	*Fine silt.*	*Clay.*
0.09	0.30	1.11	9.95	52.47	27.73	3.56	4.00



2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm.	.05-.01 mm.	.01-.005 mm.	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

UNITED STATES DEPARTMENT OF AGRICULTURE,

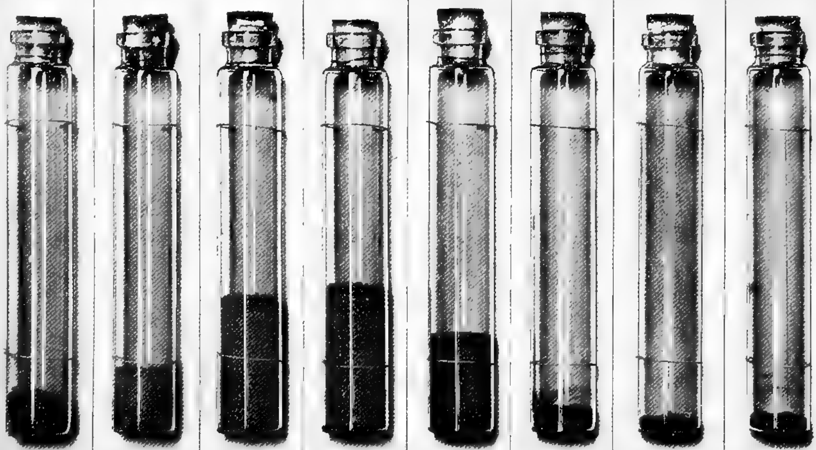
DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL TRUCK LAND AT PROVIDENCE, RHODE ISLAND.

No. 516.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand.*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt.*	*Fine silt.*	*Clay.*
7.35	11.02	23.17	24.52	17.45	4.79	1.88	1.62



2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm.	.05-.01 mm.	.01-.005 mm.	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

18

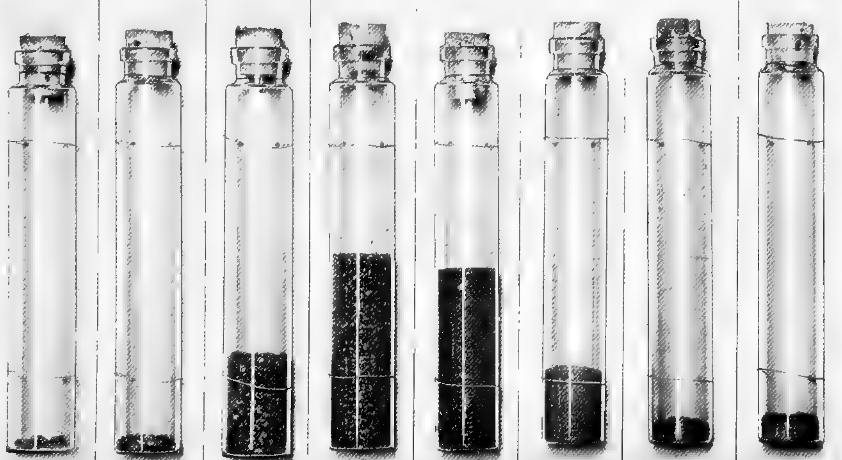
UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL TRUCK LAND AT BOSTON, MASSACHUSETTS.

No. 508.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.							
Gravel	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand*	*Silt*	*Fine silt*	*Clay.*
0.65	3.56	15.25	30.07	29.31	12.02	1.52	2.64



.2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm.	.05-.01 mm.	.01-.005 mm.	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

19

UNITED STATES DEPARTMENT OF AGRICULTURE,

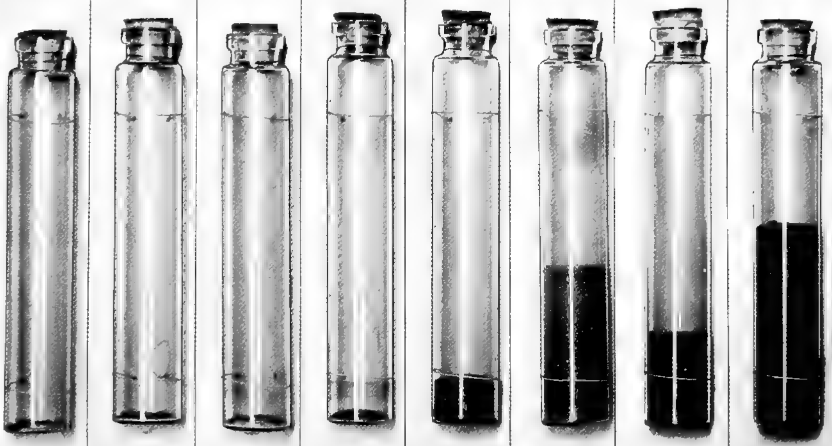
DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL TOBACCO LAND OF THE TRENTON LIMESTONE FORMATION AT MARIETTA, PENNSYLVANIA.

No. 1360.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand.*	*Medium sand.*	*Fine sand*	*Very fine sand.*	*Silt*	*Fine silt*	*Clay.*
0.12	0.21	0.27	0.37	7.48	28.28	16.24	35.80



2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm.	.05-.01 mm.	.01-.005 mm.	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

20

UNITED STATES DEPARTMENT OF AGRICULTURE.

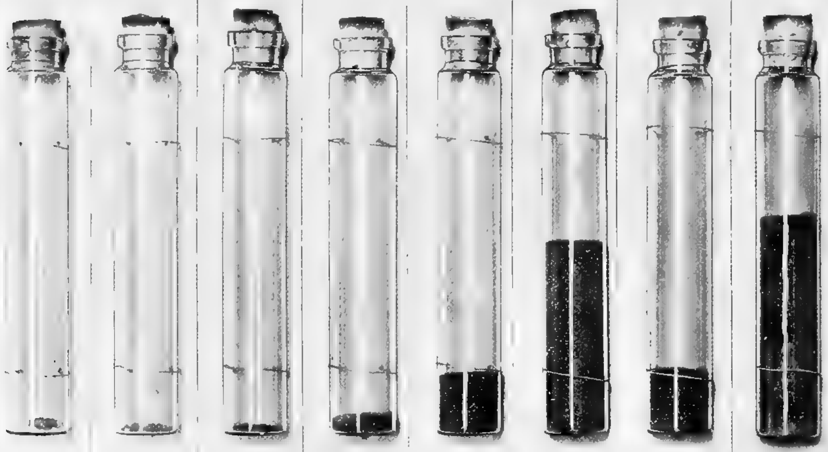
DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL TOBACCO LAND OF THE TRENTON LIMESTONE FORMATION AT LITITZ, PENNSYLVANIA.

No. 16.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	[illegible]	Medium sand	Fine sand	Very fine sand	Silt.	Fine silt	Clay
0 06	0 40	0 93	3 11	11.45	30.55	10.35	36 30



2-	1-.5	.5-.25	.25-.1	.1-.05	.05-.01	.01-.005	.005-.0001
		mm.	mm.	mm.	mm.	mm.	mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

TEXTURE OF SOME IMPORTANT TYPES OF TOBACCO SOILS.

TOBACCO LANDS OF PENNSYLVANIA.

Tobacco has been a very important crop on the limestone soils of Pennsylvania, where a dark, heavy cigar wrapper is produced, of the same general type as the Cuban leaf. When dark cigars are in style, our domestic supply of wrappers comes mainly from these heavy limestone lands. When light-colored cigars are in demand, as at present, the domestic supply comes mainly from the lighter loamy soils of Pennsylvania and from the light sandy soils of the Connecticut Valley.

These limestone soils contain, as a rule, from 30 to 50 per cent of clay. They are extremely fertile, being admirably adapted to wheat and grass.

TOBACCO LANDS OF THE CONNECTICUT VALLEY.

The characteristic tobacco of the Connecticut Valley is grown upon light sandy soil bordering the Connecticut River and having the same general texture as the early truck soils of the Atlantic Coast. The tobacco produced upon these light soils has a light color and a moderately thin-textured leaf with small ribs and veins. It resembles the Sumatra type, with which it has to compete.

The percentage of clay in the soil has a marked effect upon the color and texture of the wrappers. As a rule, soils containing the least amount of clay produce the lightest and finest-textured wrappers. The yield per acre is less than on the heavier soils, but the crop brings a better price per pound.

The illustrations of the tobacco soils of Poquonock and East Hartford, Conn., and of Hatfield, Mass., show the texture of the finest type of tobacco lands of the Connecticut Valley. There are soils in the Connecticut Valley containing a very large amount of silt (55 to 65 per cent), and although they contain but a small percentage of clay the soil is close and heavy and very retentive of moisture. Tobacco grows very coarse and rank on these soils, and the wrappers are unsuited to our domestic markets at present. If, however, the style should change and dark cigars again come in fashion, these soils would again be cultivated in tobacco, and the light, sandy soils would have to be abandoned.

Illustrations are given showing the average amount of water maintained by the soils at Poquonock, where the light wrappers are produced, and of the heavy, limestone soil at Marietta, Pa., where the dark wrappers are grown. The Connecticut Valley soils contain about 7 per cent of moisture, while the other contains 18 per cent.

21

UNITED STATES DEPARTMENT OF AGRICULTURE,

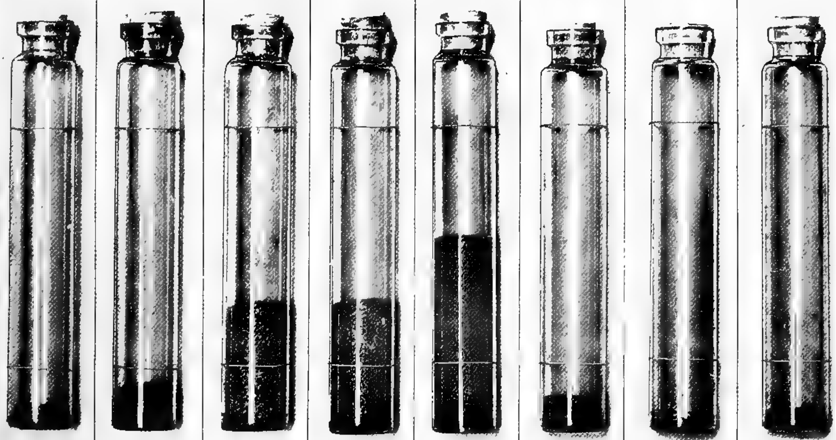
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL TOBACCO LAND AT POQUONOCK, CONN.

No. 1254.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand.*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt.*	*Fine silt.*	*Clay.*
3.22	7.53	19.63	23.76	34.50	5.92	0.78	2.53
2-1 mm	1-.5 mm.	.5-.25 mm.	.25-.1 mm	.1-.05 mm.	.05-.01 mm.	.01-.005 mm	.005-.0001 mm.



DIAMETER OF THE GRAINS IN MILLIMETERS.

22

UNITED STATES DEPARTMENT OF AGRICULTURE,

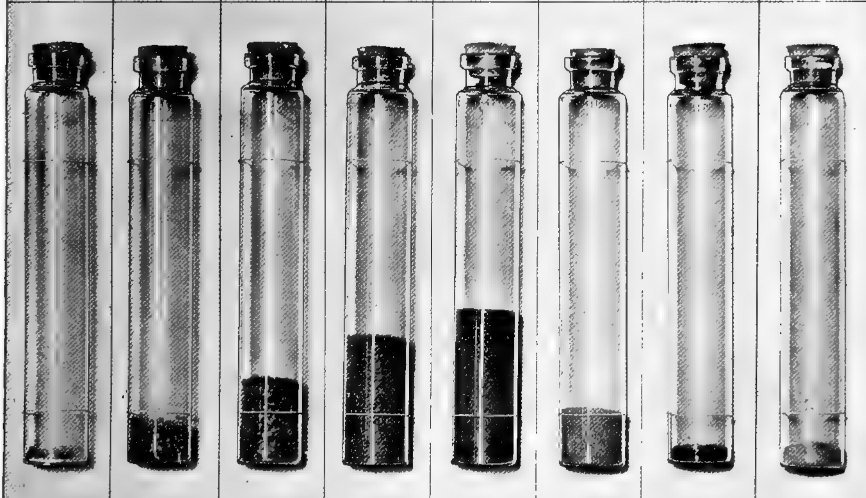
DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL TRUCK LAND AT EAST HARTFORD, CONNECTICUT.

No. 842.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Course sand.*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt.*	*Fine silt.*	*Clay.*
1.05	5.03	18.31	25.83	32.11	11.31	1.15	2.51



2-1 mm	1-.5 mm	.5-.25 mm	.25-.1 mm	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.

23

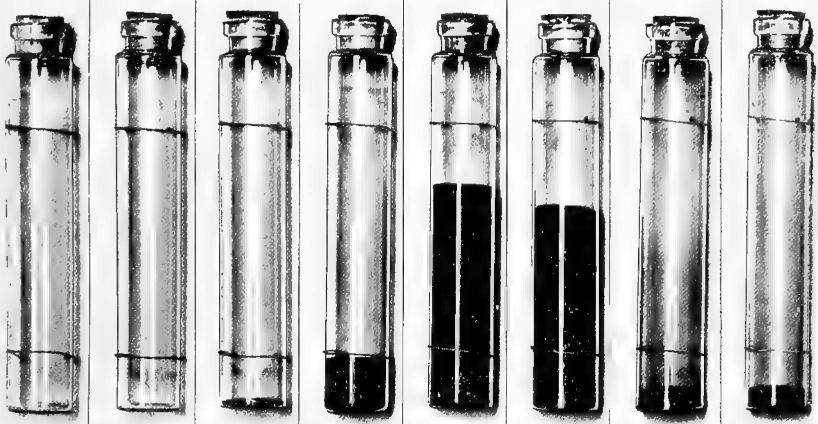
UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL TOBACCO LAND AT HATFIELD, MASSACHUSETTS.

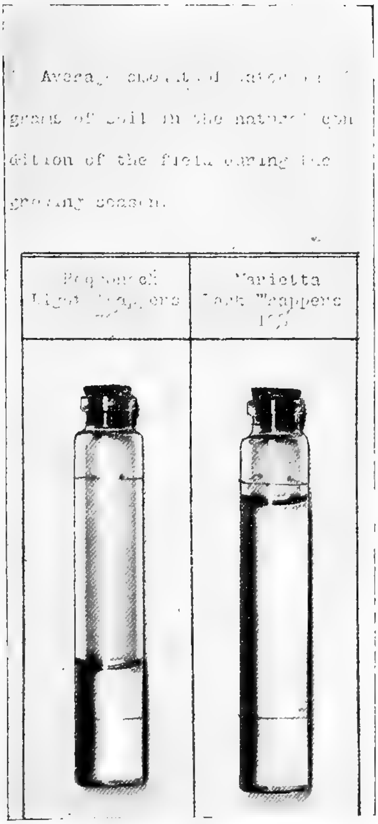
No. 1173.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.							
Gravel.	*Coarse sand.*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt.*	*Fine silt.*	*Clay*
0.00	0.00	0.40	9.00	42.12	38.90	3 07	3.17



2-1 mm	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.


Marietta

TOBACCO LANDS OF CUBA.

Samples of tobacco soils have been received from a number of districts of Cuba, including the Vuelta Abajo, Santa Clara, Remedios, Gibara, Mayari, and Yara districts. The samples were received with little information or description, and there has been no personal examination of the lands by an expert from this division. Until this is done and the soils and other conditions of these districts have been thoroughly examined it will not be safe to generalize much from the limited amount of data which has been obtained.

Six samples have been examined from the Vuelta Abajo district and four from the Remedios district around Camajuani. The samples from each of these localities are very uniform, and it is believed that they represent somewhat closely the typical soil conditions. An illustration is given of the texture of a sample from each of these two districts.

It will be noticed in examining the illustrations that the soils of the famous Vuelta Abajo district contain very little clay, ranging from 2.60 to 9.35 per cent in the six samples which have been examined. The soils have comparatively little silt, but contain from 35 to 55 per cent of very fine sand. The texture of these soils is not unlike that of the tobacco soils of the Connecticut Valley.

The soils adapted to the Remedios tobacco are very much heavier. Three of the samples examined contain from 34.85 to 37.71 per cent of clay, the other containing only about 19 per cent. The Remedios tobacco is very much stronger and darker than that grown upon the lighter soils of the Vuelta Abajo district, as would be expected from the difference in the texture of the soils. The samples of the Remedios tobacco soils examined are quite similar in texture to the tobacco soils of the limestone area of Pennsylvania.

Only one or two samples have been received from each of the other tobacco districts of Cuba, and the data obtained does not warrant any generalization at this time.

TOBACCO LANDS OF SUMATRA.

Several samples of soil have been examined from Sumatra, all of them said to be well adapted to the best type of Sumatra wrappers. They are from the following estates: Taudjong Geoneung, Rimboen, and Behalla. The texture of the sample from the Rimboen estate, which seems to be an average, is shown in one of the following illustrations. This is evidently of volcanic origin, as much of the coarser material consists of fragments of pumice.

These samples contain from 1 to 12.75 per cent of clay, the rest of the mineral matter being quite evenly distributed between several grades of sand and silt. The sample which is shown here contains 23.41 per cent of organic matter and over 12 per cent of moisture in the air-dry sample. Another sample contained over 26 per cent of organic matter, while two samples from the Behalla estate contained about 9 and 10 per cent.

The texture of these soils is not very different from the texture of the tobacco soils of the Connecticut Valley, except in the amount of organic matter they contain. The climate, of course, is very different and for this reason the soil conditions are undoubtedly dissimilar.

25

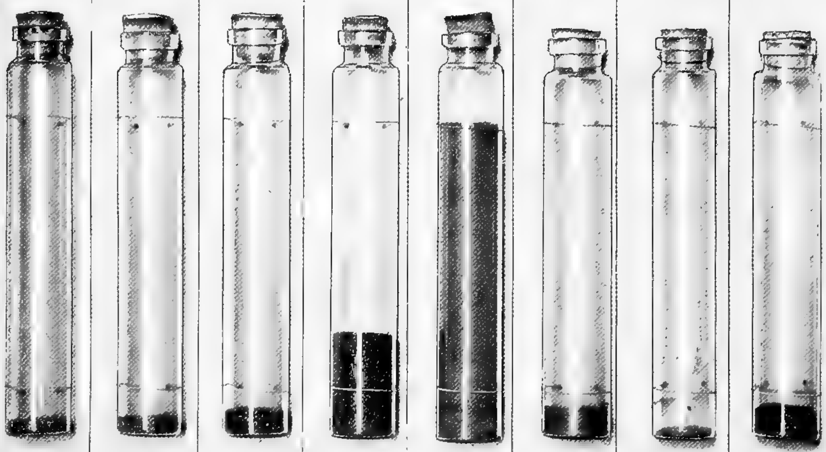
UNITED STATES DEPARTMENT OF AGRICULTURE.

THE TEXTURE OF A TYPICAL TOBACCO LAND OF THE VUELTA ABAJO DISTRICT, CUBA.

No. 309.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand.*	*Silt.*	*Fine silt*	*Clay.*
3.45	2.80	4.50	18.70	55.80	5.11	1.04	5.34



2-1 mm	1-.5 mm	5-.25 mm	.25-.1 mm	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.

26

UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF AGRICULTURAL SOILS

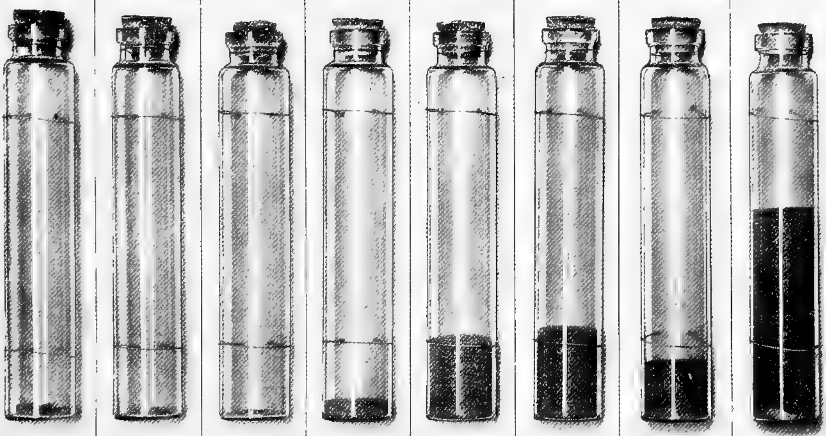
THE TEXTURE OF A TYPICAL TOBACCO LAND ADAPTED TO REMEDIOS TOBACCO,

FROM CAMAJUANI, CUBA.

No. 1960.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand.*	*Medium sand.*	*Fine sand*	*Very fine sand.*	*Silt*	*Fine silt.*	*Clay.*
0.65	0.25	0.30	3.20	14 05.	17 91	11.81	37.10



2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm.	.05-.01 mm.	.01-.005 mm.	.005.-0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

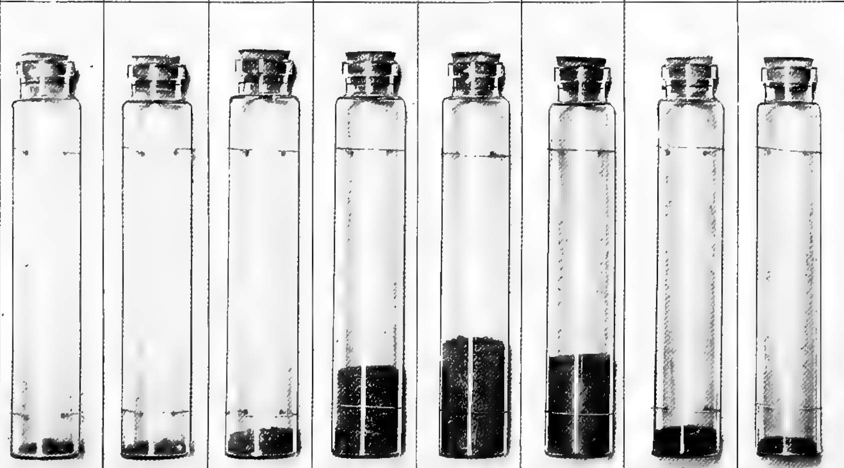
27

UNITED STATES DEPARTMENT OF AGRICULTURE,
DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL BRIGHT TOBACCO LAND FROM THE RIMBOEN ESTATE, SUMATRA.

No. 2200.

Per [illegible] Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.							
[illegible]	[illegible]	[illegible]	Fine sand	Very fine sand	Silt	Fine silt	Clay
[illegible]	[illegible]	[illegible].62	1[illegible].94	19.52	18.82	4.69	2.72



2-1 mm	[illegible]-.5	.5-.25	.25-.1 mm	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

28

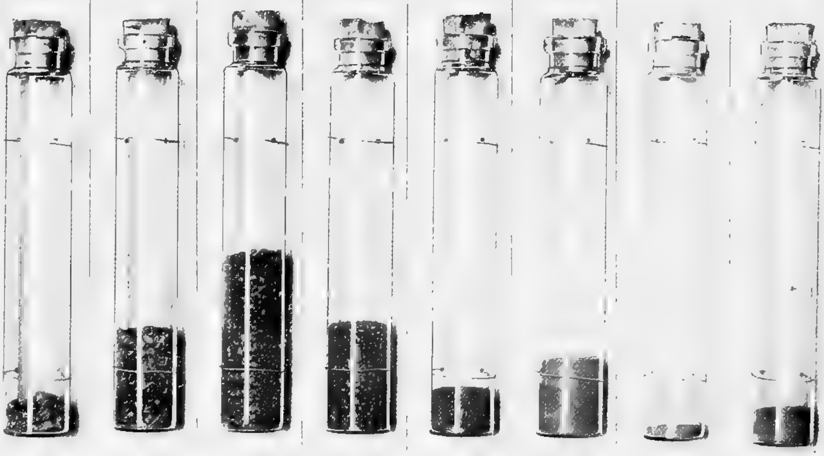
UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF AGRICULTURAL SOILS

THE TEXTURE OF A TYPICAL BRIGHT TOBACCO LAND AT LANCASTER, SOUTH CAROLINA.

No. 764.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil							
Gravel	*Coarse sand*	*Medium sand*	*Fine sand.*	*Very fine sand*	*Silt.*	*Fine silt*	*Clay*
6.41	17.48	29.66	17.18	7.14	12.86	2.05	4.05



2-1	1-.5	.5-.25	.25-.1	.1-.05	.05-.01	.01-.005	.005-.0001

DIAMETER OF THE GRAINS IN MILLIMETERS.

UNITED STATES DEPARTMENT OF AGRICULTURE,

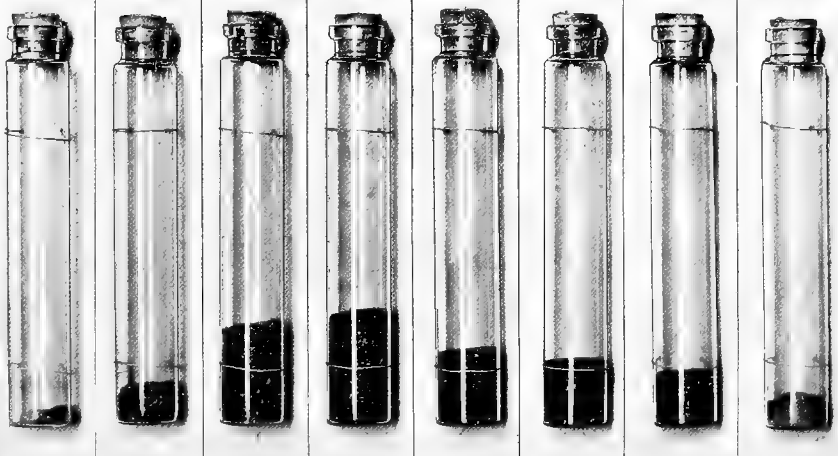
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL BRIGHT TOBACCO LAND IN GRANVILLE COUNTY, NORTH CAROLINA.

No. 759.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand.*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt*	*Fine silt.*	*Clay.*
3.09	7.16	21.74	22.92	16.76	13.17	8.24	4.80



2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm.	.05-.01 mm.	.01-.005 mm.	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

UNITED STATES DEPARTMENT OF AGRICULTURE,

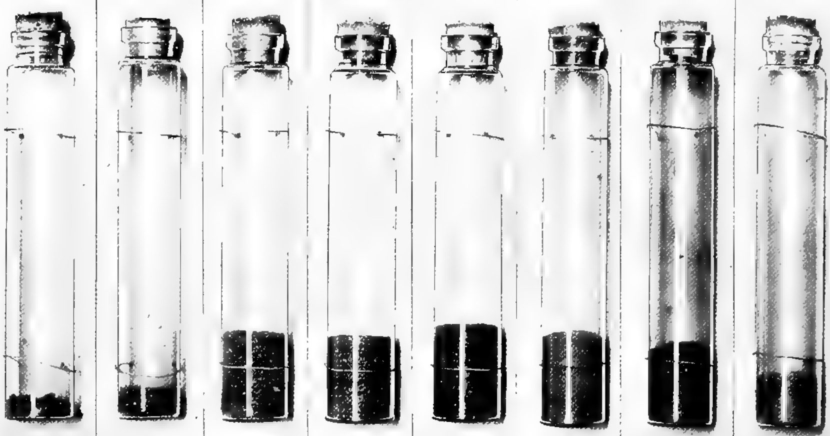
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL BRIGHT TOBACCO LAND OF THE KNOX SANDSTONE FORMATION IN GREENE COUNTY, TENNESSEE.

No. 779.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	*Coarse sand*	*Medium sand.*	*Fine sand*	*Very fine sand.*	*Silt.*	*Fine silt*	*Clay.*
3.54	5.04	14.60	15.77	17.36	17.47	16.82	8.13



2-1 mm	1-.5 mm.	.5-.25 mm	.25-.1 mm	.1-.05 mm.	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.

31

UNITED STATES DEPARTMENT OF AGRICULTURE,

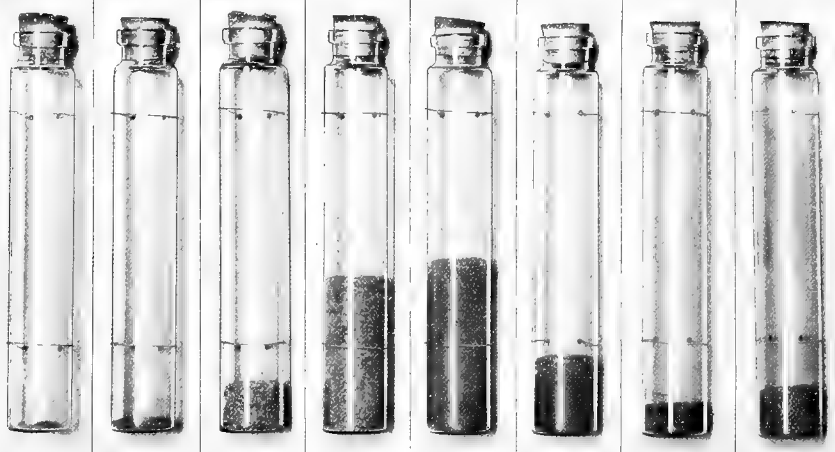
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A TYPICAL BRIGHT TOBACCO LAND AT DANVILLE, VIRGINIA.

No. 1372.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand*	*Medium sand.*	*Fine sand*	*Very fine sand*	*Silt*	*Fine silt.*	*Clay.*
0.14	0.74	8.07	28.26	32.16	13.95	5.11	9.17



2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm.	.05-.01 mm.	.01-.005 mm.	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

BRIGHT-TOBACCO LANDS OF THE SOUTH.

Samples of the soils adapted to bright tobacco have been collected from many localities in West Virginia, Virginia, North and South Carolina, Louisiana, and Tennessee. The soils recognized by practical farmers to be adapted to this crop in these several States have the same texture—very light sandy soils containing not over 10 per cent of clay and composed largely of the medium grades of sand. Four illustrations are given, showing the texture of the bright-tobacco soils in as many States.

Investigations have been made of the amount of water contained in these soils, and it has been found that the most favorable growing conditions are when the soil has between 6 and 8 per cent of moisture. When the soils contain more than 10 per cent of moisture, they are too wet for the crop, and the plants are inclined to be coarse textured and dark colored. When the soils contain less than 5 per cent of moisture, crops suffer. If the deficiency is not too marked, the plant has a finer texture, and a brighter color can be given in the curing, but while the quality is thus improved the yield per acre is very much less, and it is a question whether the increased value of the crop per pound compensates for the smaller yield per acre.

The tobacco produced on these light sandy soils is used for cigarettes, chewing tobacco, and light grades of smoking tobacco.

EXPORT-TOBACCO LANDS OF THE SOUTH.

There are great areas of land in Virginia, North Carolina, Tennessee, and Kentucky where heavy, dark-colored types of tobacco are grown. Some of these are suitable for growing smoking and chewing tobacco for our domestic markets, but many of them are unsuited to our domestic needs. These are shipped to England, France, Germany, Italy, Austria, and other foreign countries. The type of tobacco adapted to several of these foreign markets differs considerably. It is found in practice that the tobaccos adapted to these different purposes and different markets are grown upon different types of soil, as the soil conditions determine in a very marked degree the character of the tobacco produced. There has not been enough detailed work done on the shipping tobacco soils to enable an intelligent classification to be made and types established representing the soils best adapted to the different types of tobacco. The lands are all heavier than the bright tobacco lands, and as a rule the more retentive they are of moisture the darker and heavier the type of tobacco produced. The cultivation of tobacco has been given up on large areas of heavy clay lands, as the tobacco raised thereon was too dark and strong for any of our present needs. A medium grade of clay loam is at present used for the shipping tobaccos. Two illustrations are given, showing the texture of a shipping tobacco in the Clarksville district of Tennessee and near Newstead, Kentucky.

It will be noticed that these soils contain a very large amount of silt and only about 20 per cent of clay. They are quite similar in texture to the loess soils of the West. They contain much more clay than the bright tobacco soils, but this is not a measure of their retentiveness of water, for the large amount of silt has a marked influence upon the water-holding power of soils, as was pointed out in describing the loess soils of the West.

These medium-grade shipping tobacco soils maintain on an average about 15 per cent of moisture for plants.

32

UNITED STATES DEPARTMENT OF AGRICULTURE,

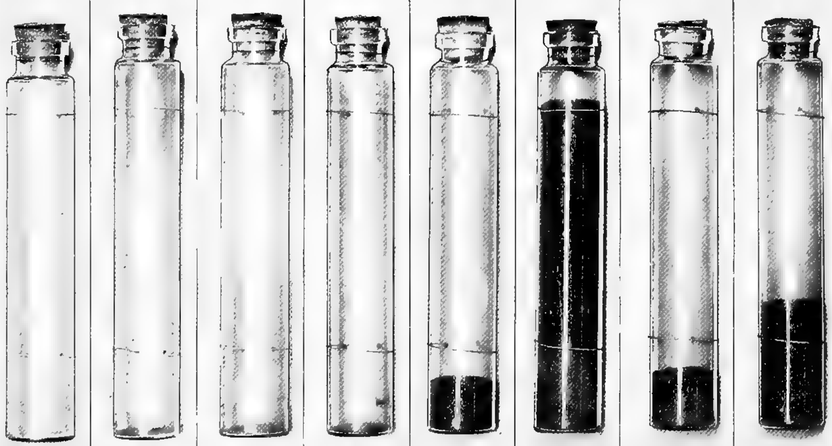
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A DARK SHIPPING TOBACCO LAND NEAR CLARKSVILLE, TENNESSEE.

No. 1720.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand.*	*Silt*	*Fine silt*	*Clay.*
0.00	0.04	0.13	0.91	8.46	56.46	8.98	19.38



2-1 mm.	1-.5 mm.	.5-.25 mm.	.25-.1 mm.	.1-.05 mm.	.05-.01 mm.	.01-.005 mm.	.005-.0001 mm.

DIAMETER OF THE GRAINS IN MILLIMETERS.

UNITED STATES DEPARTMENT OF AGRICULTURE,

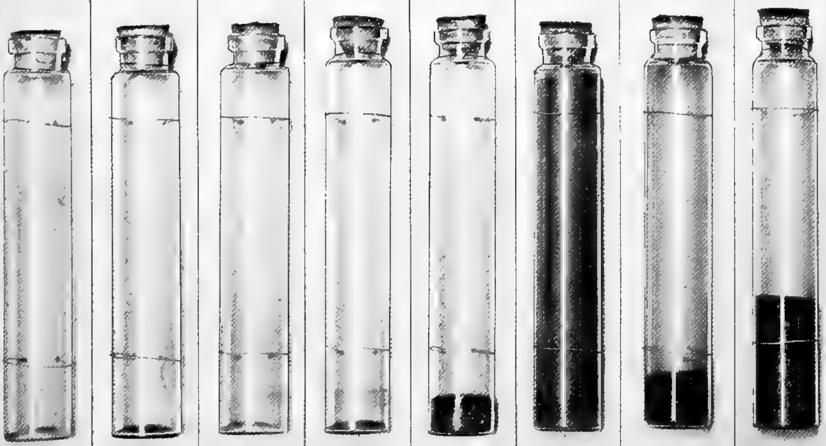
DIVISION OF AGRICULTURAL SOILS.

THE TEXTURE OF A DARK SHIPPING TOBACCO LAND OF THE BARRENS FORMATION AT NEWSTEAD, KENTUCKY.

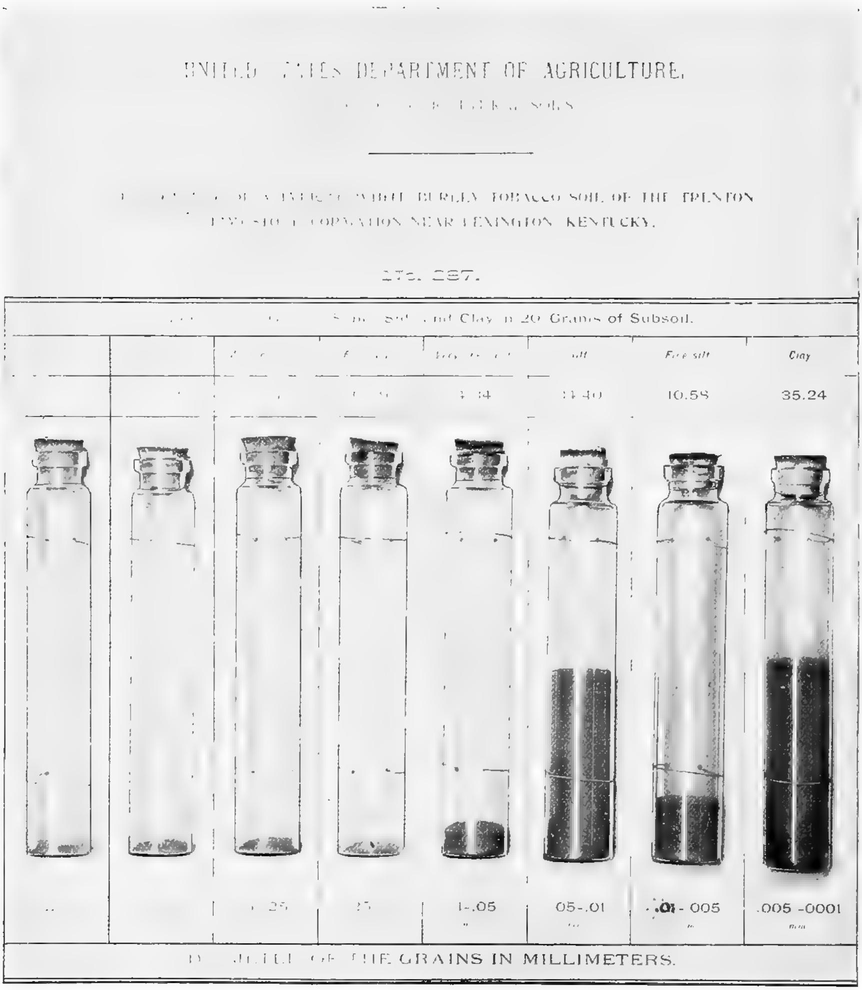
No. 1099.

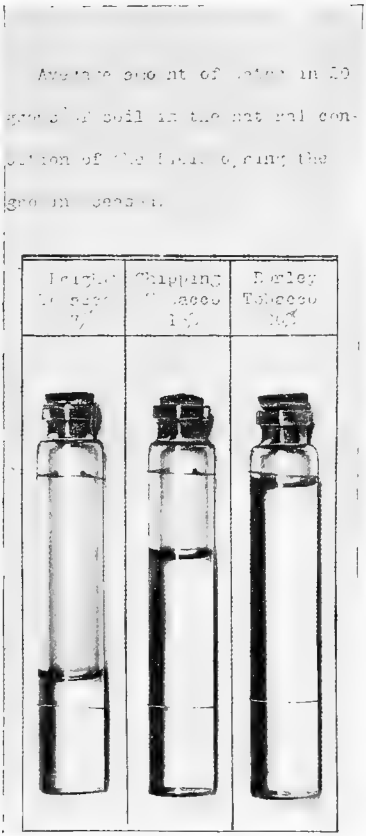
Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	*Coarse sand*	*Medium sand*	*Fine sand*	*Very fine sand*	*Silt*	*Fine silt*	*Clay*
0.05	0.18	0.11	0.34	5.13	63.28	5.19	20.55
2-1 mm.	1-.5 mm	.5-.25 mm	.25-.1 mm	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm.



DIAMETER OF THE GRAINS IN MILLIMETERS.


DEPARTMENT OF AGRICULTURE.
KENTUCKY.
Clay in 20 Grams of Subsoil.
Fine silt
Clay
10.58
35.24
05-.01
.01-.005
.005-.0001
GRAINS IN MILLIMETERS.


Chipping
Tobacco

WHITE BURLEY TOBACCO LAND.

The White Burley tobacco, used largely for smoking and chewing, is grown upon the very heavy limestone soils of Tennessee, Kentucky, and Ohio. The soil maintains a uniformly large supply of moisture, and the plant makes a very large, rank growth. An illustration is given showing the texture of a typical White Burley tobacco land in the limestone soils near Lexington, Ky.

An illustration is also given showing graphically the relative amount of water maintained in equal weights of the soils adapted to these three classes of tobacco.

BULLETIN No. 6. S. 8.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF SOILS.

AN ELECTRICAL METHOD

OF

DETERMINING THE MOISTURE CONTENT OF ARABLE SOILS.

BY

MILTON WHITNEY, FRANK D. GARDNER, AND LYMAN J. BRIGGS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1897.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS,
Washington, D. C., March 11, 1897.

SIR: I have the honor to transmit herewith a description of an electrical method of determining the moisture content of arable soils. This is the first of a series of three bulletins descriptive of methods of soil investigation. They are necessarily technical, and are intended mainly for those interested in the development of soil investigation.

I recommend that this be published as Bulletin No. 6 of this Division.

Respectfully,

MILTON WHITNEY,
Chief of Division.

HON. JAMES WILSON,
Secretary of Agriculture.

TABLE OF CONTENTS.

ILLUSTRATIONS.

AN ELECTRICAL METHOD OF DETERMINING THE MOISTURE CONTENT OF ARABLE SOILS.

INTRODUCTION.

For a long time the importance of having a reliable and convenient method for determining the amount of moisture in soils has been recognized. It has been pointed out a number of times that the rain does the plant little positive good until it enters the soil, where it can be absorbed by their roots. The rainfall record furthermore does not necessarily indicate the character of the season, for an abundant rainfall poorly distributed may give a very poor growing season, while a small rainfall properly distributed may give an exceedingly favorable season. A record of the actual amount of water in the soil from day to day would, on the other hand, give the absolute value of the moisture conditions under which plants are growing, and even without reference to the rainfall data it would show, if the character of the soil was understood, whether the conditions were favorable or otherwise for the crop.

All crops do not need the same amount of water, but, on the contrary, different classes of crops and different agricultural interests require very different conditions as regards moisture.

The geographic and geologic features of a country, especially the location of large bodies of water, the elevation and direction of mountains, and the prevailing winds determine to a great extent the climate and particularly the rainfall of a country. As a result of this there are large areas which, by reason of their position, have a high rainfall or which are deficient in this respect.

While these physiographic conditions control the general climatic conditions of a locality they are not the only conditions which control the moisture supply of plants, for if the soil of these large areas were perfectly uniform there would be a monotonous uniformity in the character of the crops which could be economically produced. Fortunately there is a great variety of soil conditions. Soils differ very markedly in their texture and physical properties, so that even with the same amount of rain falling on adjacent fields the texture of the soil of one field may be so open and porous as to let most of the rainfall descend rapidly, while the soil of the other field may be so close and retentive as to hold a very much larger volume of water at the disposal of crops. There are thus in these different kinds of soils conditions suited to different classes of plants, and by taking advantage of them and adapting our crops and methods to these natural conditions we have that opportunity for a great diversity of crops and agricultural interests which gives strength and independence to an agricultural community.

It is necessary therefore for the most perfect development of the agricultural possibilities of any soil that we should be able to determine the moisture content of the soil in order that we may select the crops best suited to the existing natural conditions, or that we may be able to control these conditions to a certain extent through methods of cultivation, fertilization, and irrigation.

In greenhouse culture the florist maintains very different conditions of both moisture and temperature for lettuce, tomatoes, violets, carnations, and even for the different varieties of roses; so different, indeed, are the conditions adapted to these several crops that he must have separate houses in order that the conditions may be properly controlled. It is an exceedingly valuable thing to realize that in nature we have just as different conditions in soils of different texture and that it is only through an appreciation of this that the highest development of any community may be assured.

The only method of determining the moisture content of soils in general use is the very simple one of taking a sample of the soil from the field at any desired depth and drying it at the ordinary temperature of the air or at the temperature of 100° to 110° C. This method, as used by this Division, has been described in Bulletin No. 4. The method is neither convenient nor accurate. From long experience we have found that, owing principally to the inequalities in the field and to the difficulty of taking representative samples, the method is not reliable for a single determination to within 2 per cent above or below the actual amount determined by twenty or thirty duplicate observations; that is, for any single determination there is a plus or minus error of 2 per cent apparently irrespective of the amount of water present. This is from 7 to 30 per cent of the actual amount of water usually present in soils, so that the results of single determinations are not accurate to within 16 per cent on the average of the actual amount of water in the soil.

Various other methods have been proposed for the determination of the amount of moisture in soils, but with very slight success. It is desirable, of course, on account of the inequalities of the soil, to have a method which will determine the variation in the amount of moisture at a particular place and depth in the field. Several methods were tried at the New York Experiment Station and described at length in the annual report for 1886. Bricks were buried about 8 inches deep in the soil and taken up from day to day and weighed. This method, besides being very inconvenient, was found to be entirely unreliable. The bricks were not able to absorb more than half as much water as the soil would contain. Porous terra cotta was then tried, but while it was found that this would absorb quite as much water as the soil it would not give it up readily after being saturated by rains. Finally a method was devised which, with some modifications, has been used at other places. A graduated tube is let down into the soil for a few inches, and water is allowed to flow out through a small opening either directly into the soil or into a piece of porous tile. It is assumed that more water will leave the graduated tube in a dry soil than in a wet one, and the quantity which flows out in a certain time will bear some proportion to the amount of water contained in the soil. This method has never yet proven entirely satisfactory or reliable.

The possibility of using the electrical resistance of soils for the determination of moisture, which forms the subject of the present bulletin, was suggested some years ago by the necessity of thoroughly grounding lightning rods, telephones, and telegraph lines. If these are not carried to a considerable depth so that the terminals are constantly in a moist soil, the lines do not work in dry seasons, since the current can not readily pass off when the soil around the terminals becomes dry. Such a method seemed particularly desirable, for if it could be perfected electrodes could be permanently buried in the soil, to remain undisturbed during the entire season, and by measuring the resistance to the passage of a current through the soil the amount of moisture in the soil could be determined. This suggestion was taken up about ten or twelve years ago, and has been worked on as opportunity permitted until the present time. The investigations were thus started before the modern conceptions of the nature and principles of salt solutions and of electrical conductivity had been developed. Much of the data obtained, therefore, was entirely inexplicable at that time, and it is only in the light of modern investigations in the field of physical chemistry that it has been possible to carry the work to a successful termination.

At present we look upon the soil as a difficultly soluble compound, and upon the soil moisture as a salt solution derived therefrom. By treating the moisture from the standpoint of a solution and following the modern ideas of physical chemistry on the nature of salt solutions an entirely new conception is thrown upon the nature of soils and several new lines of investigation are pointed out.

SOLUBILITY OF SOILS.

Soils are composed of fragments of various minerals and salts, each more or less soluble in water. Even the quartz grains are slightly soluble, especially in water containing carbonic acid, as the soil waters usually do. The solution of solids is quite analogous to the evaporation of liquids. In the presence of water the different minerals and salts constituting the soil throw off molecules of their substance into the liquid. Many of these molecules in moving through the liquid fall again upon the surface of similar undissolved matters and are thus withdrawn from solution. When the number of molecules thrown out from the solid is exactly equal to the number which fall on the solid from the solution a neutral condition is maintained which is called saturation.

In the case of a mixture of different minerals and salts, as in the soil, the solubility of each is nearly independent of the presence of the others. The actual amount of each one of these mineral substances which can be dissolved before a condition of saturation is reached depends upon the solution pressure on the surface separating the mineral from the solvent, just as the evaporation of the solution depends upon the vapor pressure at the surface of the liquid. A saturated solution of some minerals and salts therefore may contain a large weight of the substance, while with other difficultly soluble compounds the saturated solution contains only a minute quantity of the solid. It is easy to see, therefore, that a saturated solution of silica or of other difficultly soluble minerals in the soil may be formed when water is added to the soil, while the actual amount of mineral in solution is extremely small.

The solubility of minerals and salts and the saturation coefficient, like the evaporation of liquids, is dependent upon the temperature, the rate and extent of diffusion, and upon some other conditions of which we know comparatively little. It follows, therefore, that the concentration of the soil moisture can not be a very constant quantity nor a very simple thing. When a certain amount of pure water is mixed with a soil all the constituents of the soil are dissolved to a greater or lesser extent. Of the readily soluble minerals and salts, possibly all which come in contact with the liquid are dissolved, and so far as they are concerned the solution is still far from saturation. With the more difficultly soluble compounds, however, the slight amount of substance actually dissolved really forms a saturated solution. Slight changes in temperature will disturb the balance and cause more of the compounds to go either into or out of solution.

It is apparent that when more water is introduced into the soil the salt solution will be diluted, the solution pressure will be diminished, and more of the solid substances will be dissolved until the concentration again increases and the solution pressure is again equal to the pressure on the surface of the solid. On the contrary, when water is withdrawn from the soil through evaporation or transpiration through plants, the concentration of the solution is increased and a portion of the difficultly soluble salts will be thrown out of solution on the solid again until an equilibrium in pressure is attained. We should thus expect that the concentration of the soil moisture as well as the actual amount of salt in the soil will vary constantly with every change in the conditions affecting the solubility of such difficultly soluble compounds.

THE NATURE AND ELECTRICAL PROPERTIES OF SOLUTIONS.

For the purpose of the present investigation the soil is considered as a difficultly soluble compound, and it will be studied through the salt solutions in accordance with the nature and electrical properties of solutions as developed in the recent work in physical chemistry.

The present theory of the nature and electrical properties of solutions as they bear upon the soil investigations may be briefly stated. When common salt is dissolved in water the salt undergoes a partial dissociation—that is, a portion of the molecules in solution are broken down into part molecules, or ions, so that the solution will contain sodium ions, and chlorine ions, besides a number of sodium chloride molecules. These ions carry enormous charges of electricity, and it is upon these ions that the electric conductivity of solutions depends. The more dilute the solution the greater the proportion of dissociation of the molecules until the solution contains one gram equivalent of salt (i. e., a weight of the substance in grams numerically equal to its molecular weight) in a thousand liters of water or a thousandth normal (*n/1,000*) salt solution, when the dissociation is practically complete. Solutions of most of our common salts of the same molecular concentration, for example, a tenth normal (*n/10*) sodium chloride solution and a tenth normal (*n/10*) potassium nitrate solution containing an equal number of chemical equivalents per cubic centimeter have nearly the same specific electrical resistance and conductivity.

The specific resistance of a solution is a resistance of one cubic centimeter of the liquid between parallel electrodes each having an area of one square centimenter placed one centimeter apart. The specific conductivity as used in this bulletin is the reciprocal of the specific resistance. For example, the specific resistance of a *n/10* sodium chlorid solution is about one hundred ohms at 24° C. The specific conductivity, therefore, would be 0.01 of a unit of conductivity at this temperature. The unit of conductivity is the reciprocal of the ohm. It has no specific name. The conductivity of a solution depends directly upon the dissociated molecules or ions present; the undissociated molecules are inert and play no part whatever in the electrical conductivity.

Since solutions of like molecular concentration have the same number of chemical equivalents, and since these chemical equivalents carry equal electrical charges, all simple salt solutions of the same molecular concentration and temperature would have the same conductivity, except that the degree of dissociation is not exactly the same and that the ions themselves have somewhat different velocities. A solution of one-half the concentration of another contains one-half as many molecules, but rather more than half as many ions because of the greater dissociation in the dilute solution. The specific conductivity of such a solution would therefore be a little more than half of the first solution.

The following table[1] shows the variation in the specific electrical resistance, the molecular conductivity, and the extent of dissociation of a number of the salts commonly found in the soil or applied to it as fertilizers in solutions of equal molecular concentration at a uniform temperature of 18° C.

[1] Compiled from the work of F. Kohlrausch.

The specific resistance and molecular conductivity of salt solutions of different strength.

Molecular volume.	Specific resistance.	Molecular conductivity.	Salt dissociated.	Salt not dissociated.	Molecular volume.	Specific resistance.	Molecular conductivity.	Salt dissociated.	Salt not dissociated.
$NaCl$					KCl				
1,000	9,338	107.1	100.0	0.0	1,000	7,889	126.8	100.0	0.0
100	978	102.3	95.5	4.5	100	821	121.9	96.1	3.9
10	109	91.9	85.8	14.2	10	88	111.3	87.7	12.3
1	13.5	73.9	69.0	31.0	1	10.2	97.7	77.0	23.0
$NaNO_3$					KNO_3				
1,000	9,876	101.3	100.0	0.0	1,000	7,970	125.5	100.0	0.0
100	1,037	96.4	95.2	4.8	100	838	119.3	95.1	4.9
10	115	86.8	85.7	14.3	10	96	104.5	83.3	16.7
1	15	65.6	64.8	35.2	1	12.5	79.9	63.7	36.3
½Na_2CO_3					½K_2CO_3				
1,000	9,984	110.2	100.0	0.0	1,000	7,680	129.8	100.0	0.0
100	1,047	95.5	86.7	13.3	100	869	115.1	88.7	11.3
10	138	72.5	65.8	34.2	10	107	93.4	71.9	28.1
1	22	45.4	41.2	58.8	1	15.2	66.0	50.8	49.2
⅓H_3PO_4					½K_2SO_4				
1,000	9,701	102.9	100.0	0.0	1,000	7,795	128.3	100.0	0.0
100	1,190	84.0	81.7	18.3	100	857	116.7	91.0	9.0
10	219	45.7	44.4	55.6	10	105	954.0	74.4	25.6
1	47.1	21.3	20.7	79.3	1	14	714.0	55.7	44.3

The molecular volume of the first column expresses the concentration of the solution. A molecular volume of ten indicates that the solution contains an amount of salt expressed in grams numerically equivalent to the molecular weight, dissolved and diluted to ten liters, thus making a tenth normal (*n/10*) solution. The molecular conductivity is the conductivity of a quantity of the solution containing one gram molecule, placed between parallel electrodes one centimeter apart. The molecular conductivities, as given in the table, are multiplied by one thousand. In order, therefore, to obtain the real values, the decimal point will have to be moved three places to the left. The last two columns of the table show the percentage of dissociated and undissociated salts in the solutions, assuming that in a solution of *n/1,000* the dissociation is complete.

It will be noticed that the sodium and potassium carbonates and potassium sulphates have twice the conductivity of the other salts, while phosphoric acid has three times the conductivity. This is because one of the ions formed by the dissociation of these salts carries two or three times as great an electric load as the others.

Temperature plays an important part in the conductivity of a solution, for between certain limits of temperature the resistance decreases or the conductivity increases as the temperature rises. This is due to the influence of temperature on the dissociation and on the frictional resistance which the fluid offers to the passage of an ion through it. As the dilution increases and the dissociation becomes more nearly complete the effect of the temperature on the dissociation becomes less and less, and finally vanishes when the dissociation is complete.

There are, therefore, three principal factors which influence the electrical conductivity of soils, and which as a rule are constantly changing, namely, the temperature, the water, and the soluble salt; in other words, the amount and concentration of the salt solution and the temperature. Therefore, to determine the temperature of the soil, the water content, or the amount of salt dissolved in the water, it is necessary to know two of these three values at the time of observation in order to establish the other.

Advantage was taken of the influence of temperature on the resistance of solutions to construct a temperature cell, which is essentially a salt solution inclosed in a hermetically sealed glass tube, in which neither the salt nor the water can change. The solution used has the same temperature coefficient as the soil, so that the variation in the electrical resistance of this cell when buried in the soil will give the temperature of the soil; or, if it is used as one arm of the Wheatstone bridge in place of one of the standard comparison coils, it will eliminate the temperature effect altogether in measuring the electrical resistance of the soil. The same cell, therefore, will thus answer a double purpose.

THE BRIDGE BOX FOR MEASURING SOIL RESISTANCES.

For the measurement of the electrical resistance of the soil the Wheatstone bridge method is used with the alternating current and a telephone to indicate when a balance has been obtained. For the measurement of resistances in the field it is necessary to have an instrument sufficiently accurate, and yet with a very wide range. It must at the same time be portable, substantial, compact, and light. The instrument illustrated in figs. 1 and 2 is the outcome of long experience in both the field and laboratory.

The box is of half-inch maple, 13 inches long, 11 inches wide, and 4½ inches in height. When closed, as represented in the figure, the working parts are protected from dust and injury. The only part exposed is the current interrupter or "make-and-break" apparatus of the induction coil, which must be exposed for convenience in adjustment. This is seen in a recess on the right-hand side of the box. To the right of the recess are placed the two binding posts for battery connections, with the battery switch beneath. The connections for the telephone are on the opposite side.

The bridge consists essentially of a rheostat, comparison coils, induction coil, and a watch receiver telephone, with suitable electrical connections. One arm of the bridge contains a 1,000-ohm comparison coil, a second arm contains a 900-ohm coil and a 100-ohm coil connected in series, while the third arm contains the rheostat.

The rheostat contains 102 10-ohm coils, each coil separately adjusted and soldered to suitable contact studs arranged in two concentric circles, with an arm to make contact with successive points. These contacts are mounted for insulation in a hard rubber plate, and must be accurately spaced and so adjusted that contact is made or broken within $\frac{1}{10}$ of a division on the scale on either side of a middle point between the scale divisions. The sliding contact, consisting of two shoes formed of spring brass, must work freely and without noise, making perfect contact with every point. Contact is made with one point before it is broken with another, so that the circuit is not interrupted. The two extra 10-ohm coils are added for convenience in measuring resistances near the 1,000-ohm, or zero, point on the scale.

By means of the switch represented in the left-hand corner of the closed box, four 1,000-ohm coils can be successively connected in series with the rheostat, so that the total resistance can be varied from 0 to 5,020 ohms. This switch when standing at the upper 0 or to the right

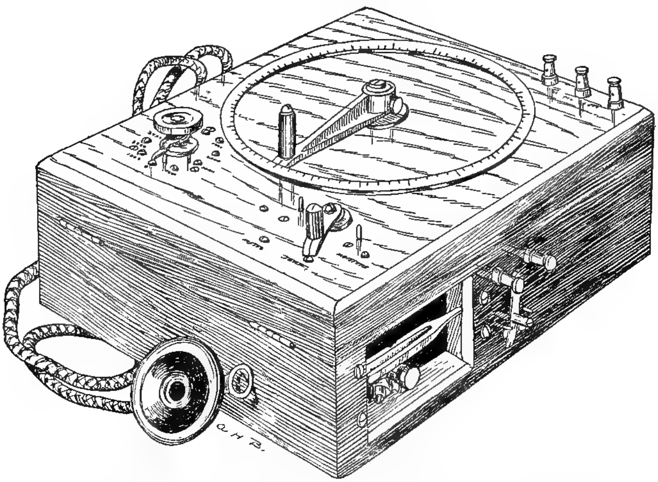


FIG. 1.—Bridge box employed in measuring the resistance of soils.

of it short circuits the 900-ohm coil in the second arm of the bridge, which changes the ratio of the bridge arms to 1 to 10, and thus increases the range of the box tenfold.

The resistance to be measured is attached by means of lead wires to the binding posts marked "Plates." The temperature cell between the electrodes is attached to the posts marked "Cell," one binding post being used in common. When the switch in the right-hand corner of the box stands at "Temperature" the temperature cell is thrown in as the unknown resistance for the purpose of taking the temperature of the soil. When it stands at "Plates" the soil electrodes are thrown in so that the resistance of the soil itself forms the fourth arm or unknown resistance of the bridge. When the switch stands at "Moisture" the soil remains as the unknown resistance, while the 1,000-ohm comparison coil is thrown out and the temperature cell is substituted for it as one arm of the bridge in order that temperature effects shall be eliminated.

The two switches described are formed of brass segments, insulated on hard rubber, with movable arms suitably connecting these segments. All switch connections and contacts are made inside the box, which is dust proof. All the comparison coils are wound accurately to within one-tenth of 1 per cent. The 10-ohm resistance coils are wound in a single layer to diminish capacity and self-induction and must not be out more than 1 ohm between 0 and 1,000.

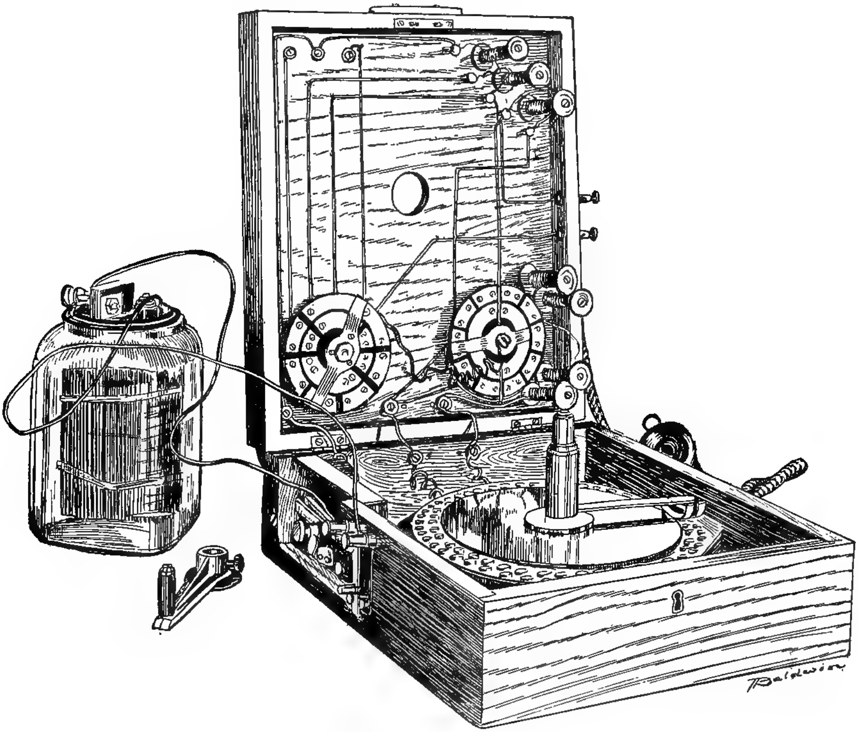


FIG. 2.—Interior of bridge box.

The induction coil is small, since little current is desired and that of rather low potential. The vibrator or contact breaker consists of a small tuning fork or single reed, driven by means of the induction coil, giving not less than 400 vibrations per second. One prong of the fork passes in front of the induction coil core, about one-sixteenth of an inch distant, and carries a very flexible spring of phosphor bronze tipped at its free end with platinum. A set screw rigidly attached to the base of the induction coil makes contact with the spring. The induction coil must be capable of giving a clear, musical note in the telephone, of high pitch and free from rasping or grating sounds.

The contact arm in the rheostat is connected to a handle and pointer on the top of the box. This pointer works over a scale graduated to 10 ohms. By removing the pointer the cover of the box can be lifted for the purpose of cleaning the contacts.

A good watch receiver telephone, inclosed in a hard rubber case with as little metal exposed as possible, is provided with each instrument, with a flexible cord for electrical connection with the binding posts. The box is shown open in fig. 2 to give an idea of the arrangement of the interior.

TEMPERATURE-COMPENSATING CELLS.

As the electrical resistance of a salt solution is influenced by the temperature, it is necessary to know the exact temperature of the layer of soil in which the resistance is to be taken and to correct the resistances accordingly, or that a method be devised by which this temperature influence may be eliminated in taking the resistance. Numerous objections have been urged against thermometers for determining the temperature of the soil at different depths, and, besides, the use of thermometers would have necessitated the correction of all resistances so as to reduce them to a uniform temperature. A much more convenient method has been devised for eliminating the temperature effect, based upon the influence of temperature on the electrical resistance of an electrolyte. This method as used to determine the temperature of soils will be more fully described in Bulletin No. 7 of this Division. For use in the method of moisture determination it is unnecessary to standardize the cells, although it is advisable of course to determine the temperature as well as the moisture of soils.

The compensating cell as it is used in this method for eliminating the temperature effects on the electrical resistance of the soil consists of a small glass tube, about 3.5 millimeters in internal diameter, with platinum electrodes fused into each end, the cell being nearly filled with a salt solution. The electrodes are made of No. 25 platinum wire twisted at one end into flat spirals which are parallel to each other in the cell and are 3 inches apart. The spiral should be plated with a good coat of platinum black to make the minimum in the telephone sharper. The salt solution consists of 90 per cent of four-fifths normal sodium chloride solution and 10 per cent commercial alcohol. This has approximately the same temperature coefficient as the soil. Lead wires are soldered to the ends of the platinum electrodes.

The method of determining the temperature coefficient of soils and the standardization and calibration of these cells for use in determining the temperature of soils will be given in Bulletin No. 7.

SOIL ELECTRODES.

The electrodes finally adopted for field work consist of carbon plates, each 3 inches long, three-eighths of an inch wide, and three-sixteenths of an inch thick. Each electrode is copper plated on one end, and an insulated No. 20 copper wire soldered to the plating of a length sufficient to reach above the surface of the ground to the measuring instrument. The carbon strips after being electroplated and having the wires attached are soaked for some time in distilled water to remove any salts or acids which may have accumulated during the plating and soldering. Two of these electrodes with wires attached are then mounted on the face of a wedge shaped wooden block, which is made in two pieces and fitted together by means of a tongue and groove. These blocks when put together are 6 inches long, $1\frac{1}{4}$ inches wide, and seven-eighths of an inch thick. The back is slightly curved, while the front is flat with a groove in the center for the temperature cell. Before use the blocks should be painted with a heavy coat of asphalt varnish. The electrodes are cemented to the block on either side of the temperature cell by means of marine glue.

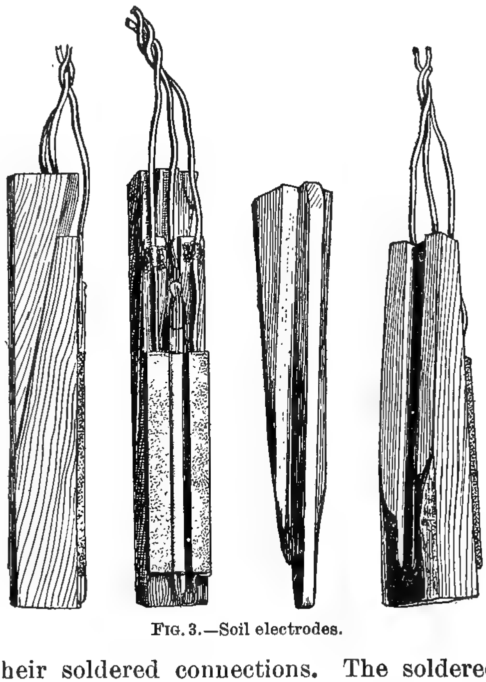


FIG. 3.—Soil electrodes.

One of the carbon electrodes must have been previously electroplated at the bottom end also, and to this the bottom platinum wire of the temperature cell is soldered. The upper electrode of the cell is soldered to a copper wire similar in insulation and as long as those fastened to the carbons. The wires should be fastened to the block by small staples, so that in handling they will be less liable to be broken from their soldered connections. The soldered parts and exposed wire of the temperature cell, together with all of the copper plating, must be insulated by covering with sealing wax, so that there will be no current through the soil except by way of the carbon electrodes. When mounted the edges of the carbons are filed down even with the block and their faces slightly rounded so as to nearly fit the curvature of a $1\frac{1}{2}$-inch hole. The wire leading from the temperature cell should have the number of the cell permanently attached, preferably on a piece of metal. The depth to which each set is to go will determine the length of the lead wires. Fig. 3 shows a set of these electrodes mounted and one of the blocks taken apart. The insulation is left off the electrodes to show more clearly the connections.

The surface of the ground, being exposed directly to climatic changes, is subject to such great and such sudden variations in electrical resistance, as well as to cultural methods, that the surface electrodes have to be considerably modified to suit the conditions for depths less than 3 inches. The top inch of soil is subject to considerable change in level, due to the action of winds, rains, and cultivation, and for most cultivated plants it serves more as a mulch and protection for the lower depths than as a feeding place for the roots of plants. For this reason it has seemed best to adopt from 1 to 3 inches as the shallowest depth at which to determine the moisture.

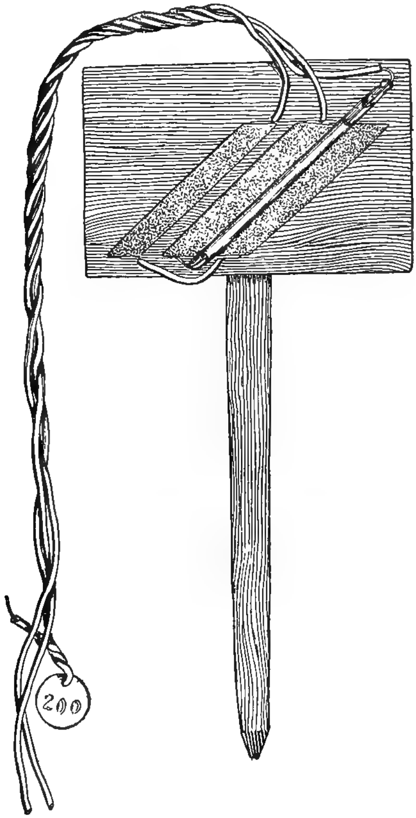


Fig. 4.—Surface electrodes.

The electrodes used for the surface have three or more carbon electrodes instead of two. They are mounted diagonally on a thin piece of board, 3 by 5 inches in dimensions, so that when the ends of the electrodes are cut diagonally across the perpendicular height will be 2 inches. The outside carbons are connected at their lower end by a wire soldered to an electro-plated surface, while the bottom platinum wire of the temperature cell is soldered to the bottom of the middle electrode. Wires are then attached to one of the outside carbons and to the inside carbon, as well as to the upper electrode of the temperature cell. A stake is provided which can be driven into the ground until the top of the board is level with the surface, when the top of the electrodes and the top electrode of the temperature cell will be 1 inch below the surface. All the wood must be well protected by asphalt varnish. This form of electrode is shown in fig. 4, without the insulation.

MODE OF BURYING ELECTRODES IN THE SOIL.

To bury electrodes for field use an ordinary 1½-inch wood auger is extended to a length of three or more feet and a hole is bored vertically in the soil to a depth to which the lowest set of electrodes is to be placed. A piece of wood or metal 3 feet long and not over an inch in diameter, with a screw fitted in one end, is used to insert the electrodes into the auger hole. The two parts of the block upon which the electrodes are mounted are held together by a rubber band. The pole is screwed into the top end of the back piece of the block. The depth to which they are to go is then marked off on the wires and the electrodes are carefully lowered into the hole. The wires are then held firmly in one hand while the pole is pressed down with the other. This causes the wedge-shaped back of the block to slide upon the other, and forces the electrodes and the cell close against the side of the hole. By tapping the pole gently with a hammer the electrode may be firmly embedded in the soil, when the pole may be unscrewed from the block and the electrodes left in position with the three lead wires coming to the surface. The wires from each set of electrodes must be permanently marked with the number of the cell and the depth at which they are placed.

Several sets of electrodes may in this way be put at different depths in the same hole, or if they are to be placed close together two holes can be used. When they are all in position the hole is filled with melted pitch to prevent water from accumulating, and at the same time to thoroughly insulate the wooden blocks and wires.

To bury the surface electrodes in the field an excavation is made to a depth of 3 inches, leaving one perpendicular side. The stake is then driven into the ground, so that the carbon plates and temperature cell are close to the perpendicular wall. The loose dirt is then packed firmly around the back of the electrodes. Care must be taken not to disturb these surface electrodes even by stepping on the soil in the immediate vicinity, for this not only changes the structure of the soil and its relation to water, but also brings a greater amount of soil within the area through which the current passes.

CONNECTIONS AND USE OF BRIDGE BOX IN FIELD WORK.

The selection of a site for taking the moisture observations in a soil, together with the treatment which the land should receive, has been fully discussed in Bulletin No. 4 of this Division. Plats should, as a rule, be laid off to insure a sufficient space around the instruments to protect them from injury and in order that the proper conditions may be uniformly maintained over a certain area.

The electrodes should be buried in the center of the plat. The depth at which to place various sets of electrodes depends upon the nature of the investigation. If it is desired to study from a large number of plats the comparative effects of different fertilizers or methods of cultivation on the conservation of soil moisture, the expense, labor, and time necessary for making the observations must be considered. In this case a single depth and a single set of electrodes for each plat will probably be sufficient. When one set of electrodes only is used it should be placed at a depth corresponding to 3 to 6 inches below the surface. Where only a few plats are to be studied more electrodes should be put in, at 1 to 3 inches, 9 to 12 inches, and 21 to 24 inches. These four depths are those adopted for study by this Division where it is feasible to have so many observations taken.

If the observations are taken on or near the plats, the wires from the electrodes should be brought together to a switchboard for convenience in connecting them with the measuring apparatus. The Western Union form of pin switch is the simplest and cheapest for this purpose. It should consist essentially of three parallel brass bars and three rows of brass disks, mounted on a hard-wood base seven-eighths of an inch thick, and reenforced so that it shall not warp. The wires from the soil electrodes and temperature cells are connected to the disks by means of the nuts at the back of the board. The free electrode should be attached to a disk on the top row. The electrode soldered to the temperature cell should be attached to the middle row, while the wire from the temperature cell should be attached to the bottom row of disks. The number of disks and the length of the bars will depend, of course, upon the number of sets of electrodes to be joined up. The parallel bars are connected by insulated wires to the proper binding posts of the bridge box.

When the plugs are all out of the switchboard there is no connection between the bars and the disks, and no connections, of course, between the buried electrodes and the bridge box. Connections can, however, be made either with the temperature cell to take the temperature of the the soil, or with the electrodes alone, or with the electrodes and the temperature cell thrown in as one arm of the bridge, to eliminate temperature effects.

The apparatus is inclosed in a substantial wooden box with a suitable lock and handle, so that it can be carried or shipped to the field. The switchboard is placed on the inside of the cover and attached by flexible insulated wires to the bridge box and to the wires from the soil electrodes. The telephone is to be connected to the binding posts on the left-hand side of the box, and the battery, consisting of one or two good, dry cells, or preferably of one or two Gonda cells, connected to the binding posts on the right-hand side of the box.

Insert the plugs for the proper connections with the ground and close the battery switch, which should start the vibrator. Place the telephone to the ear, and if the buzzing sound is not heard slightly adjust the set screw in front of the vibrator, and if necessary spring the vibrator a little with the finger in order to set it going. By slightly adjusting the set screw a clear, shrill note can be obtained. Care must be taken not to run the set screw too violently against the spring contact, as it is liable to injure the spring.

The switch at the right-hand corner of the bridge box is placed on the point marked "moisture" or "temperature," as the case may be;

then the left-hand switch is turned, so as to reduce the sound in the telephone as much as possible. Then the arm of the rheostat is moved about the graduated circle until a point is found at which the sound in the telephone is very indistinct. By moving the arm on either side of this point the sound is found to increase, and by quickly moving the arm back and fourth over this point it may be located very exactly. This minimum in the telephone shows when the balance has been attained. The number of thousands of ohms, indicated by the switch on the left hand side of the box, added to the hundreds of ohms, which the pointer indicates on the circle of the rheostat, gives the resistance in the soil which is desired. When the switch on the left-hand side of the bridge box is on the upper 0 or to the right of it, the ratio of the bridge coils is changed, and the reading of the rheostat must be multiplied by 10.

When the reading for one depth is completed the plugs in the switch board are moved so as to connect the instrument with any other depth desired.

If the note in the telephone is so loud as to interfere with the location of the minimum sound, it can generally be lessened by adjusting the set screw. It is due to too much current, and can be remedied also by introducing resistance into the battery circuit or by reducing the number of cells. When the vibrator refuses to give a clear note in the telephone, the contacts between the set screw and the spring have become fouled and should be carefully cleaned with a piece of fine emery paper. If through long use the platinum tip in the spring of the vibrator which comes in contact with the set screw is worn out, the vibrator should be taken out and a fresh piece of platinum soldered on the tip. At times the handle of the rheostat should be taken off and the top of the box thrown back and the contact studs cleaned with very fine emery. A little attention to these details will greatly facilitate the satisfactory operation of the instrument.

If the bridge box has to be located a considerable distance from the plots, or if plots from widely different localities are to be joined by lead wires to a single place of observation, the wiring will assume large proportions and will be quite an item of expense. In order to reduce the amount of wiring a different form of switch may be used in which the connections with the ground electrodes are made by mercury contacts between platinum tips projecting into hermetically sealed glass tubes. Three of these tubes, corresponding to the three lead wires from each depth, are mounted on a block, which can be tipped up by a suitable arrangement by pulling a wire from the point of observation. Any number of these contacts can thus be made, and this form of switch necessitates only three wires from the switch to the measuring box with one wire or string for making the proper connections. A very simple tumbling switch box, arranged for six sets of electrodes, on these principles has been constructed in the division, which is illustrated in fig. 5.

STANDARDIZATION OF FIELD ELECTRODES.

It has already been pointed out that the electrical resistance of soils is influenced by the temperature and the soluble salt content as well as by the amount of moisture. The temperature effect can be eliminated by substituting the temperature cell for one of the comparison coils in the bridge. As the salt content of the soil is liable to change during the season, and as there is at present no convenient method for recording this change in the field, it is necessary to standardize the field electrodes occasionally throughout the season by taking samples of the soil and determining carefully either the amount of moisture or the amount of soluble salt in the sample.

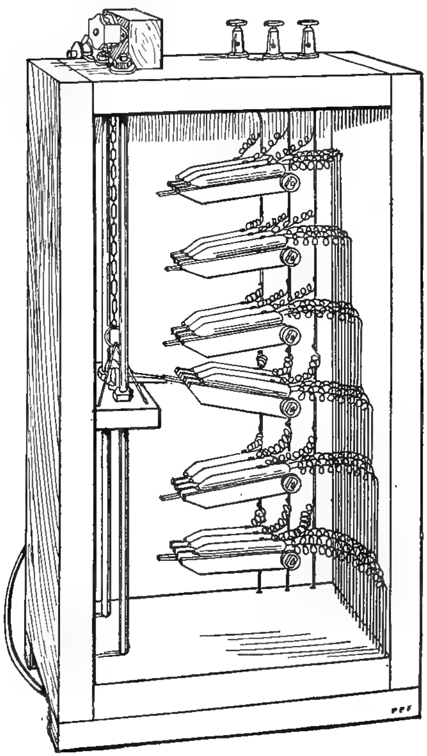


FIG. 5.—Switch box arranged for six sets of electrodes.

In artificial soils, and where the salt content does not vary, the conductivity of the soil with different percentages of water gives very nearly a straight line—that is, every percentage of water has the same value in increasing or decreasing the conductivity whether the soil is wet or dry. The data for this statement, together with a method of determining the soluble salt content of soil, will be published in another bulletin.

When the electrodes are buried, samples of the soil from at least four or five localities in the immediate vicinity should be taken at the depth corresponding to each of the electrodes. These samples should be taken in brass tubes or by augers, according to circumstances, and put into well-stoppered bottles, well mixed, and then actual moisture determinations made by drying at 110° C. Four or five days later, or when the resistance has changed sufficiently to indicate that there has been an appreciable change of the water content of the soil, another set of samples should be taken in the same way from at least four or five localities quite near the electrodes and at the same depth at which the electrodes are buried. If the soil contained, for example, 11 per cent of water at the first determination and 7 per cent at the second, the difference in conductivity, divided by the difference in the per cent of water, will give the value in units of conductivity corresponding to 1 per cent of water. This gives a constant which, if divided into the difference between any other conductivity and the conductivity when there was 11 per cent of water present, will show by how many per cent the water has changed, and if this is subtracted from 11 per cent it will give the actual water content at the time of observation. This is expressed in the following simple formula:

$$\frac{C - C_1}{p - p_1} = k$$

$$W = p - \frac{C - C_x}{k}$$

where C = the highest observed conductivity, C_1 = lowest conductivity, C_x = any other conductivity, p = per cent of water corresponding to C, p_1 = per cent of water corresponding to C_1.

This gives the value of 1 per cent of water in units of conductivity which will be used as a constant, indicated by k in the above formula, until the electrodes are restandardized.

When no abrupt or excessive changes are noticed in the resistance, as in seasons when the weather conditions are uniform or at depths not affected by slight variation in the climatic conditions, the electrodes should be restandardized at least once a month in order that the constant (k) found from the previous standardization may be changed if necessary to meet the changed conditions in the soil.

In the case of the shallow electrodes or of any electrodes which show a marked change in resistance after a rainfall, they should be immediately restandardized, and again four or five days later when the resistance indicates an appreciable change in the soil moisture, so as to get a new value for the constant k. In case only two standardizations are made during the change from one abrupt change to another, the constant thus obtained is used to integrate the readings for the whole of that period.

During the past season seven instruments have been put into the hands of practical farmers in the truck, tobacco, wheat, and grass lands of Connecticut, Pennsylvania, North Carolina, Kentucky, and Tennessee, and four very satisfactory records have been kept, covering periods of from one to three months. The work during the past season was done mainly to test the efficiency and durability of the instruments, and to see if they could be properly worked by the observers of the Division. As a result of this field experience a number of changes have been made in the instrument which are all embodied in the description given in this bulletin.

With so many other things to look after in the perfection of the method and of the apparatus, it was found impossible to properly standardize the electrodes as should have been done throughout the season.

The following table gives the record for three depths from the limestone soil near Lexington, Ky., from July 9 to October 13, together with the daily rainfall during this period. The asterisks indicate the dates on which these electrodes should have been standardized, judging from the character of the season and the variation in the resistance. This will serve to indicate the extent of variation in the resistance which is likely to occur at the several depths and to show how often restandardization should be made, at least during the preliminary study of any soil. It will probably be found as a result of continued study that the plates will need restandardizing only occasionally during the season, except in the case of very heavy rains or after the application of fertilizers. This is a matter, however, that can only be determined from the results of field experiences covering at least two or three seasons. The resistances given in the table are not the actual resistances of the field record, for the actual resistances were as high as three or four thousand ohms. For the sake of comparison, however, with the different electrodes, and in order to bring the data within such a scale that it can be plotted conveniently, the resistances have all been reduced by a constant, and while they are proportionally the same they are not actually the same as the original records.

The electrical resistance of a limestone soil near Lexington, Ky.

	July—			August—				September—				October—			
	3 6 ins.	21–24 ins.	Rain ins.	1–3 ins.	3–6 ins.	21–24 ins.	Rain, ins.	1–3 ins.	3–6 ins.	21–24 ins.	Rain, ins.	1–3 ins.	3–6 ins.	21–24 ins.	Rain, ins.
1	......	......	......	......	882	937	0.42	1,538	1,109	1,015	......	883	513	1,059	......
2	......	......	......	......	650	923	1.47	1,684	1,166	1,044	......	905	516	1,059	trace.
3	......	......	......	......	678	923	......	*460	1,147	1,000	0.33	980	548	1,059	......
4	......	......	......	......	716	926	......	874	1,166	1,015	......	1,076	566	1,059	......
5	......	......	......	......	776	941	......	903	1,166	1,015	0.09	1,133	554	1,059	......
6	......	......	......	......	834	926	......	1,039	1,160	1,015	......	*1,209	*611	1,059	0.01
7	......	......	......	......	713	926	0.57	1,153	1,179	1,015	......	1,287	631	1,044	......
8	......	......	......	......	716	955	......	1,230	1,185	1,015	......	1,363	675	1,044	......
9	758	1,115	1.59	......	......	955	......	1,307	1,164	1,030	......	1,422	720	1,059	......
10	*910	*1,042	......	......	828	955	......	*1,422	*1,211	*1,030	......	1,422	739	1,059	......
11	917	1,162	0.18	......	868	955	......	1,652	1,223	1,030	......	1,422	784	1,059	......
12	917	1,086	0.07	1,018	917	955	......	1,786	1,268	1,030	......	1,307	790	1,059	0.12
13	965	1,042	......	*903	949	955	......	1,882	1,299	1,030	0.01	537	707	1,059	0.26
14	1,000	1,102	......	980	956	955	......	2,036	1,241	1,030	......	......	......	......	......
15	*1,074	*1,115	0.03	1,192	962	955	......	1,307	1,261	1,030	0.23	......	......	......	......
16	853	1,115	0.62	1,211	962	955	0.07	1,403	1,325	1,030	trace.	......	......	......	......
17	949	1,102	......	1,346	962	985	......	1,384	1,331	1,030	trace.	......	......	......	......
18	1,009	1,026	......	*1,211	*1,000	985	......	1,499	1,389	1,030	......	......	......	......	......
19	1,089	1,073	......	1,307	1,013	1,000	......	1,786	1,376	1,030	0.02	......	......	......	......
20	788	......	1.25	1,538	1,054	985	......	1,806	1,459	1,030	......	......	......	......	......
21	757	983	2.30	788	1,045	970	0.19	1,998	1,478	1,044	0.01	......	......	......	......
22	792	953	1.03	885	1,070	1,015	......	1,981	1,536	1,044	......	......	......	......	......
23	*643	*894	1.02	*461	959	985	0.56	1,960	1,586	1,044	......	......	......	......	......
24	784	923	0.01	632	968	1,000	......	*1,978	*1,657	1,059	......	......	......	......	......
25	796	953	......	730	981	1,015	......	1,981	1,759	1,059	......	......	......	......	......
26	803	953	......	885	996	1,000	......	1,998	1,803	1,059	......	......	......	......	......
27	841	894	......	1,000	1,000	1,000	0.04	1,230	1,771	1,059	0.24	......	......	......	......
28	860	923	......	1,115	1,031	1,015	......	631	650	1,059	1.49	......	......	......	......
29	*910	*967	......	1,153	1,052	1,015	......	770	471	1,059	1.76	......	......	......	......
30	904	967	......	*1,363	1,070	1,030	......	*806	*510	1,059	0.01	......	......	......	......
31	806	966	......	1,346	1,103	1,015	......	......	......	......	......	......	......	......	......

The asterisk (*) indicates the dates on which the several electrodes should have been standardized.

The accompanying diagram (fig. 6) gives the conductivity corresponding to the resistances in the table. As before stated, it was not practicable to make moisture determinations at the actual depths of the electrodes. A single sample was, however, taken each day of the top 12 inches of the soil. This does not, therefore, correspond to the actual depth of either set of electrodes, although, as a matter of fact, the curves representing these moisture percentages agree very thoroughly with the conductivity of the electrodes at a depth of 3–6 inches below the surface. The period, as a whole, was rather dry and the rains hardly affected the deeper electrodes. The 1–3 inch electrodes show very marked changes with every rainfall, but the soil quickly dries out to an excessive degree, as would be expected. The conductivity of the 3–6 inch electrodes agrees very closely with the moisture curve, although the electrodes represent a depth of only 3 inches while the moisture is based upon a depth of 12 inches. The electrodes, 21–24 inches deep, hardly varied between August 1 and October 13, indicating very slight changes of the moisture at that depth throughout the season.

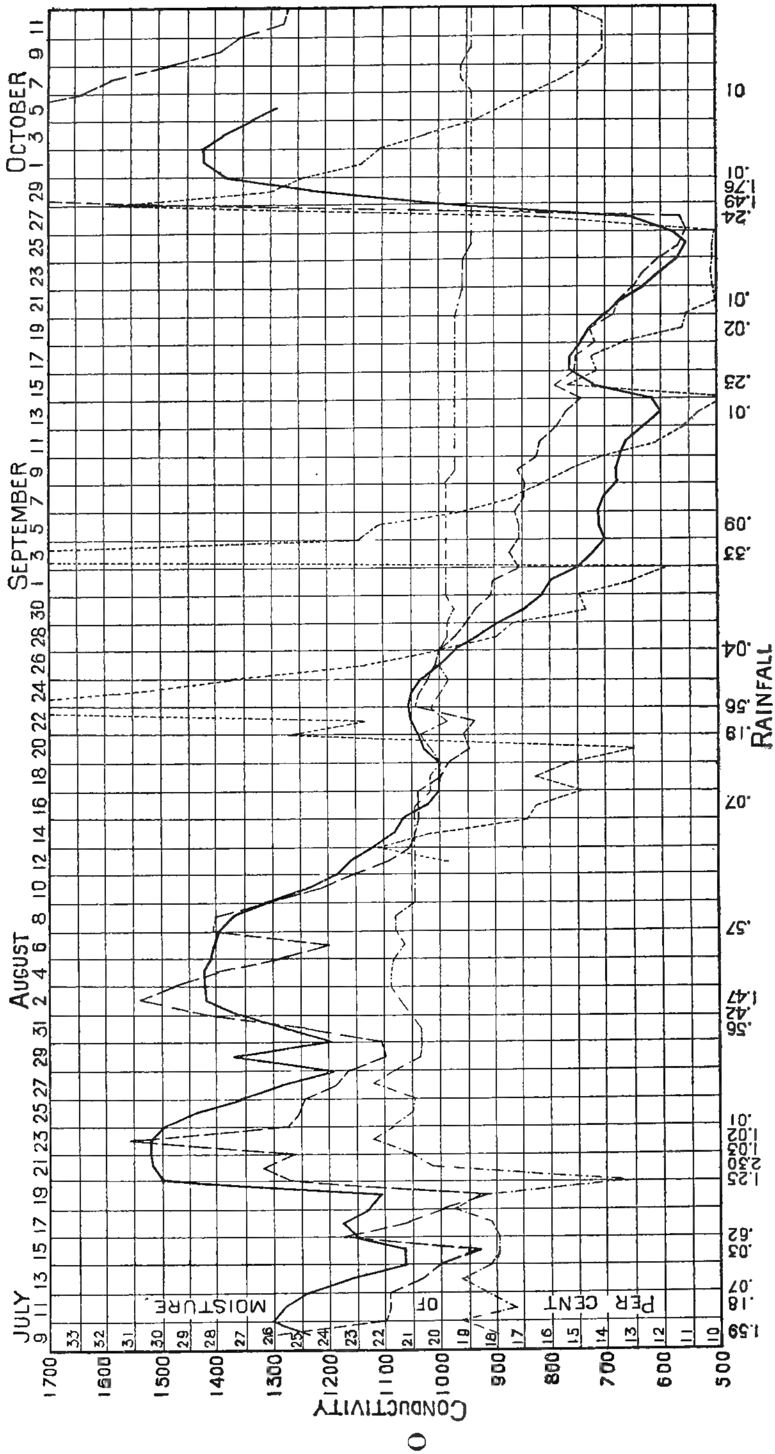
Considerable work has been done on the effect of water on the electrical resistance of soils as well as upon the influence of salts on the resistance of soils. A method has been devised for the determination of the soluble salt content of soils which is adapted to samples taken from the field. These matters will be presented in another bulletin, which will contain the essential experimental results upon which this method of moisture determination has been based.

The method, as given in the previous pages of this bulletin, requires that the resistances obtained from the measuring instrument be converted into conductivities. In order to facilitate this work a table of reciprocals is given. The use of the table will be readily understood. The resistance is given in the first column to one place of whole numbers and to one place of decimals. The second place of decimals can be obtained from the remaining columns, while the third place of decimals can be obtained by subtracting the difference corresponding to the figure found in the table of differences. If the decimal place is moved to the right or left in the resistance, it is moved an equal number of places in the opposite direction in the conductivity taken from the table. Thus,

Resistance of 5 ohms	=	conductivity		0.2
50	"	=	"	.02
500	"	=	"	.002
5,000	"	=	"	.0002

Table of reciprocals, for use in computing the electrical conductivity from the electrical resistance of soils and solutions.

Resistance, ohms.	0	1	2	3	4	5	6	7	8	9	Differences (to be subtracted). 1	2	3	4	5	6	7	8	9
1.0	1.0000	9901	9804	9709	9615	9524	9434	9346	9259	9174	8	17	25	33	42	50	58	66	75
1.1	0.9091	9009	8929	8850	8772	8696	8621	8547	8475	8403	7	14	21	28	35	42	49	56	63
1.2	8333	8264	8197	8130	8065	8000	7937	7874	7813	7752	6	12	18	24	30	36	42	48	54
1.3	7692	7634	7576	7519	7463	7407	7353	7299	7246	7194	5	10	15	20	26	31	36	41	46
1.4	7143	7092	7042	6993	6944	6897	6849	6803	6757	6711	4	9	13	18	22	26	31	35	40
1.5	6667	6623	6579	6536	6494	6452	6410	6369	6329	6289	4	8	12	16	20	23	27	31	35
1.6	6250	6211	6173	6135	6098	6061	6024	5988	5952	5917	4	7	11	14	18	21	25	28	32
1.7	5882	5848	5814	5780	5747	5714	5682	5650	5618	5587	3	6	9	12	16	19	22	25	28
1.8	5556	5525	5495	5464	5435	5405	5376	5348	5319	5291	3	6	8	11	14	17	20	22	25
1.9	5263	5236	5208	5181	5155	5128	5102	5076	5051	5025	3	5	8	10	13	15	18	20	23
2.0	0.5000	4975	4950	4926	4902	4878	4854	4831	4808	4785	2	5	7	9	12	14	16	18	21
2.1	4762	4739	4717	4695	4673	4651	4630	4608	4587	4566	2	4	6	8	11	13	15	17	19
2.2	4545	4525	4505	4484	4464	4444	4425	4405	4386	4367	2	4	6	8	10	11	13	15	17
2.3	4348	4329	4310	4292	4274	4255	4237	4219	4202	4184	2	3	5	7	9	10	12	14	15
2.4	4167	4149	4132	4115	4098	4082	4065	4049	4032	4016	2	3	5	6	8	10	11	13	14
2.5	4000	3984	3968	3953	3937	3922	3906	3891	3876	3861	2	3	5	6	8	9	11	12	14
2.6	3846	3831	3817	3802	3788	3774	3759	3745	3731	3717	1	3	4	5	7	8	9	10	12
2.7	3704	3690	3676	3663	3650	3636	3623	3610	3597	3584	1	3	4	5	7	8	9	10	12
2.8	3571	3559	3546	3534	3521	3509	3497	3484	3472	3460	1	2	4	4	6	8	9	10	11
2.9	3448	3436	3425	3413	3401	3390	3378	3367	3356	3344	1	2	4	4	6	8	9	10	11
3.0	0.3333	3322	3311	3300	3280	3279	3268	3257	3247	3236	1	2	3	4	5	6	7	8	9
3.1	3226	3215	3205	3195	3185	3175	3165	3155	3145	3135	1	2	3	4	5	6	7	8	9
3.2	3125	3115	3106	3096	3086	3077	3067	3058	3049	3040	1	2	3	4	5	6	7	8	9
3.3	3030	3021	3012	3003	2994	2985	2976	2967	2959	2950	1	2	3	4	5	5	6	7	8
3.4	2941	2933	2924	2915	2907	2899	2890	2882	2874	2865	1	2	2	3	4	5	6	6	7
3.5	2857	2849	2841	2833	2825	2817	2809	2801	2793	2786	1	2	2	3	4	5	6	6	7
3.6	2778	2770	2762	2755	2747	2740	2732	2725	2717	2710	1	1	2	3	4	4	5	6	6
3.7	2703	2695	2688	2681	2674	2667	2660	2653	2646	2639	1	1	2	3	4	4	5	6	6
3.8	2632	2625	2618	2611	2604	2597	2591	2584	2577	2571	1	1	2	3	4	4	5	6	6
3.9	2564	2558	2551	2545	2538	2532	2525	2519	2513	2506	1	1	2	2	3	4	4	5	5
4.0	0.2500	2494	2488	2481	2475	2469	2463	2457	2451	2445	1	1	2	2	3	4	4	5	5
4.1	2439	2433	2427	2421	2415	2410	2404	2398	2392	2387	1	1	2	2	3	4	4	5	5
4.2	2381	2375	2370	2364	2358	2353	2347	2342	2336	2331	1	1	2	2	3	3	4	4	5
4.3	2326	2320	2315	2309	2304	2290	2294	2288	2283	2278	1	1	2	2	3	3	4	4	5
4.4	2273	2268	2262	2257	2252	2247	2242	2237	2232	2227	1	1	2	2	3	3	4	4	5
4.5	2222	2217	2212	2208	2203	2198	2193	2188	2183	2179	1	1	2	2	3	3	4	4	5
4.6	2174	2169	2165	2160	2155	2151	2146	2141	2137	2132	1	1	2	2	3	3	4	4	5
4.7	2128	2123	2119	2114	2110	2105	2101	2096	2092	2088	0	1	2	2	2	2	3	3	4
4.8	2083	2079	2075	2070	2066	2062	2058	2053	2049	2045	0	1	2	2	2	2	3	3	4
4.9	2041	2037	2033	2028	2024	2020	2016	2012	2008	2004	0	1	1	2	2	2	3	3	4
5.0	0.2000	1996	1992	1988	1984	1980	1976	1972	1969	1965	0	1	1	2	2	2	3	3	4
5.1	1961	1957	1953	1949	1946	1942	1938	1934	1931	1927	0	1	1	2	2	2	3	3	4
5.2	1923	1919	1916	1912	1908	1905	1901	1898	1894	1890	0	1	1	1	2	2	2	2	3
5.3	1887	1883	1880	1876	1873	1869	1866	1862	1859	1855	0	1	1	1	2	2	2	2	3
5.4	1852	1848	1845	1842	1838	1835	1832	1828	1825	1821	0	1	1	1	2	2	2	2	3
5.5	1818	1815	1812	1808	1805	1802	1799	1795	1792	1789	0	1	1	1	2	2	2	2	3
5.6	1786	1783	1779	1776	1773	1770	1767	1764	1761	1757	0	1	1	1	2	2	2	2	3
5.7	1754	1751	1748	1745	1742	1739	1736	1733	1730	1727	0	1	1	1	2	2	2	2	3
5.8	1724	1721	1718	1715	1712	1709	1706	1704	1701	1698	0	1	1	1	2	2	2	2	3
5.9	1695	1692	1689	1686	1684	1681	1678	1675	1672	1669	0	1	1	1	2	2	2	2	3
6.0	0.1667	1664	1661	1658	1656	1653	1650	1647	1645	1642	0	1	1	1	2	2	2	2	3
6.1	1639	1637	1634	1631	1629	1626	1623	1621	1618	1616	0	1	1	1	2	2	2	2	3
6.2	1613	1610	1608	1605	1603	1600	1597	1595	1592	1590	0	1	1	1	2	2	2	2	3
6.3	1587	1585	1582	1580	1577	1575	1572	1570	1567	1565	0	1	1	1	2	2	2	2	3
6.4	1563	1560	1558	1555	1553	1550	1548	1546	1543	1541	0	1	1	1	2	2	2	2	3
6.5	1538	1536	1534	1531	1529	1527	1524	1522	1520	1517	0	0	1	1	1	1	1	2	2
6.6	1515	1513	1511	1508	1506	1504	1502	1499	1497	1495	0	0	1	1	1	1	1	2	2
6.7	1493	1490	1488	1486	1484	1481	1479	1477	1475	1473	0	0	1	1	1	1	1	2	2
6.8	1471	1468	1466	1464	1462	1460	1458	1456	1453	1451	0	0	1	1	1	1	1	2	2
6.9	1449	1447	1445	1443	1441	1439	1437	1435	1433	1431	0	0	1	1	1	1	1	2	2
7.0	0.1429	1427	1425	1422	1420	1418	1416	1414	1412	1410	0	0	1	1	1	1	1	2	2
7.1	1408	1406	1404	1403	1401	1399	1397	1395	1393	1391	0	0	1	1	1	1	1	2	2
7.2	1389	1387	1385	1383	1381	1379	1377	1376	1374	1372	0	0	1	1	1	1	1	2	2
7.3	1370	1368	1366	1364	1362	1361	1359	1357	1355	1353	0	0	1	1	1	1	1	2	2
7.4	1351	1350	1348	1346	1344	1342	1340	1339	1337	1335	0	0	1	1	1	1	1	2	2



Moisture, 0—12 in. ——— Conductivity, 1″—3″ .... Conductivity, 3″—6″ — — — Conductivity, 21″—24″ — · — ·

FIG. 6.—Field records of a limestone soil near Lexington, Ky.

BULLETIN No. 7. S. 9.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF SOILS.

AN ELECTRICAL METHOD

OF

DETERMINING THE TEMPERATURE OF SOILS.

BY

MILTON WHITNEY AND LYMAN J. BRIGGS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1897.

LETTER OF TRANSMITTAL.

UNITED STATES DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS,
Washington, D. C., March 11, 1897.

SIR: I have the honor to transmit herewith a description of an electrical method of determining the temperature of soils, and to recommend that it be published as Bulletin No. 7 of this Division.

Respectfully,

MILTON WHITNEY,
Chief of Division.

HON. JAMES WILSON,
Secretary of Agriculture.

TABLE OF CONTENTS.

ILLUSTRATIONS.

AN ELECTRICAL METHOD OF DETERMINING THE TEMPERATURE OF SOILS.

INTRODUCTION.

Ever since the oft-quoted experiments of Schübler, on the relation of soils to heat, agricultural investigators have been more or less interested in soil temperatures. Periodic efforts have been made to study the relation of certain soils to heat and a considerable amount of material has been accumulated, but the results have been in the main very confusing and hard to interpret. This has been due to several causes. It will be remembered that Schübler worked with air-dry samples in the laboratory and found remarkable differences in the heat capacity and radiating power of sand, clay, and humus. His results have been very misleading as applied to field conditions, which are so different from the laboratory conditions of his experiments.

In the laboratory the dry sand quickly acquires a higher temperature from the same source of heat than the clay. In the field both soils are moist. The specific heat of water being eight times greater than soil, the same source of heat would only raise the temperature of a given weight of water one-eighth of the amount it would raise the temperature of an equal weight of soil. It is therefore apparent that the amount of moisture in the two soils would probably have more to do with the temperature of the field than the difference in the specific heat of the soils. Furthermore, the proportion of the moisture resulting from rains, which is evaporated from the surface, is transpired by plants, and percolates through the soil and runs off into streams, has a very material influence upon the temperature of a soil in the field. It is a complicated problem and one which can not be reasoned out nor settled in the laboratory, but can only be determined by field records.

Is the temperature of a light sandy truck land warmer or colder than that of a stiff clay wheat or grass land? This is the simplest, as well as the most important, of the fundamental problems to be settled. The next step would be to determine if the soil in which the roots of plants are hidden is warmer or colder on the average than the conditions under which the top of the plant is growing, and whether the difference, if there is any, is constant during all the growing period of the plant.

This brings up one very important point—that temperature observations in a single soil have comparatively little value. The real value of the work is only apparent when soils of different character and different agricultural values are compared. Observations at a single depth in each of the soils of widely different character have far more value than observations at a dozen depths in the same soil. Engineers and physicists have studied the general relation of soils and rocks to heat sufficiently to establish the general laws of the periodic waves of heat which descend into the earth.

Numerous objections have been urged against the use of thermometers for taking the temperatures of soils. In the first place, the bulbs of soil thermometers are usually of an undetermined length, and as the temperature of the layers of soil are liable to vary greatly, even for very slight depths, it is difficult to know just what depth the thermometer represents, or rather it is difficult to have two thermometers represent the same depth. This has been corrected in some forms of thermometers by making the bulbs of some certain length, as 3 inches, 6 inches, and the like.

A more serious objection, however, to the ordinary form of soil thermometers is that when the bulb is more than a few inches below the surface of the ground, while the scale is above the surface, the effect of the great range of temperature near the surface on the long column of mercury in the stem is sufficient to very materially affect the result.

Where a number of thermometers at different depths in the same soil are read at the same time they will be at different parts of their daily range. Thus in North Carolina[1] it was found that the maximum temperature of the day occurred at the surface of the ground at 1 p. m.; 3 inches deep, 3 p. m.; 6 inches deep, 5 p. m.; 12 inches deep, after 7 p. m.; 24 inches deep, 7 a. m. Any observations made of the temperature at these various depths at the same moment of time might obviously be very misleading, and the results would in any case be hard to interpret.

The relative temperature of a soil is certainly one of its important physical properties, and it is important that this line of work be continued in order that some of the fundamental problems be solved. We should at least know the relative temperature of the soils adapted to our different agricultural interests.

In perfecting the electrical method for moisture determinations in soils, described in Bulletin No. 6 of this Division, a compensation cell, having the same electrical temperature coefficient as the soil is used as one arm of the Wheatstone bridge, in order to eliminate temperature effects in determining the electrical resistance of soils. Thermometers could not be used satisfactorily on account of the objections which have just been urged. Furthermore, the use of thermometers would necessitate the correction of all resistances to reduce them to a uniform temperature. This form of cell can very readily be used for taking the temperature of soils, and it obviates several of the instrumental defects of the ordinary soil thermometer.

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[1] Annual Report, N. C. Ex. Sta., 1886, p. 108.

The temperature cell consists essentially of a small glass tube nearly filled with a salt solution, with electrodes dipping into the salt solution at either end of the cell. The resistance is measured by the Wheatstone bridge method, an alternating current being employed to prevent polarization, with a telephone in place of the usual galvanometer. The resistance of the cell is more than twice as great at 32° as it is at 90° F., the resistance of electrolytes, unlike that of most metals, being higher at the lower temperature.

In order to use this cell for obtaining the temperature of a soil a simple salt solution may be used, but where the cells are to be used to eliminate the effect of variations in temperature, as in the method of moisture determinations described in Bulletin No. 6, the solution must have the same temperature coefficient as the soil, and as the cells are usually used for this double purpose it is preferable to use a solution having the same temperature coefficient as the soil.

THE TEMPERATURE-RESISTANCE COEFFICIENT OF SOILS.

In order to determine the temperature coefficient of soils, a small quantity of soil is put into a cell and regularly standardized at different temperatures. These cells are constructed of strips of glass cemented together with marine glue. They are 3 inches long, 2 inches wide, and one-half inch thick in external dimensions. The electrodes consist of two carbon strips one-half inch wide and 3 inches long, copper plated on one end. Insulated copper wires are soldered to the electrodes. The electrodes are then cemented to the glass strips forming the narrow sides of the cell, and are then filed down until only a thin strip of carbon remains. The cell is then put together by means of marine glue, with the carbon electrodes facing each other. The soil to be tested is mixed with distilled water to bring it to a condition about suitable for potting plants. A quantity of the moist soil is then firmly packed into the cell. It is advisable to add a drop or two of carbolic acid to prevent organic changes in the soil. A strip of glass is then put over the top and fastened with marine glue. The wires leading from the electrodes should be firmly attached to the outer side of the cell, to prevent injury in handling to the insulation where the wires enter the cell. The cell as thus prepared must be impervious to water, and to insure this it is well to cover it, after filling, with a second coating of marine glue.

These earth cells are then standardized at various temperatures in the same way as the glass temperature cells, which will be shortly described.

Owing to the difference in resistance of the cells, due to difference in the salt content, and the difficulty of packing the soils uniformly, the resistances of different cells can not readily be compared until they are reduced to a common standard. For this reason the resistance of each cell is so reduced as to make the resistance at 60° F. equal 1,000. This gives a ratio of change of resistance with temperature by which all cells can be readily and accurately compared. The reduction is easily made. If at 60° a cell has a resistance of 1,600 ohms all of the observed resistances of this cell should be multiplied by 1,000/1,600. If the observed resistance at 60° is 900 ohms all of the other resistances of this cell should be multiplied by 1,000 900.

The following table gives the temperature coefficient as determined from twenty-seven cells of nine typical soils of the United States:

Temperature coefficient of nine types of soil.

Kind of soil.	Locality.	32°	35°	40°	45°	50°	55°	60°	65°	70°	75°	80°	85°	90°
Red hill	South Carolina	1,638	1,527	1,382	1,265	1,162	1,076	1,000	933	869	811	758	709	664
Limestone clay *	Virginia	1,618	1,511	1,370	1,257	1,157	1,074	1,000	935	877	823	773	727	685
Gabbro	Maryland	1,613	1,507	1,366	1,254	1,156	1,073	1,000	935	874	819	767	720	677
Alkali	Colorado	1,609	1,504	1,365	1,253	1,155	1,073	1,000	935	874	818	767	719	673
Adobe	New Mexico	1,602	1,498	1,360	1,250	1,153	1,072	1,000	937	876	822	772	725	683
Loam	Maryland	1,595	1,492	1,356	1,247	1,151	1,071	1,000	938	878	824	775	729	687
Export tobacco†	Kentucky	1,590	1,488	1,353	1,245	1,150	1,071	1,000	937	876	822	772	725	683
Truck	Maryland	1,586	1,482	1,351	1,244	1,149	1,070	1,000	940	882	830	782	738	697
Loess	Illinois	1,576	1,476	1,345	1,240	1,147	1,069	1,000	936	875	821	770	724	681
Mean		1,601	1,497	1,360	1,250	1,153	1,072	1,000	937	877	823	773	727	685

* Trenton limestone. † Subcarboniferous.

These soils represent some of the extreme types found in the United States, so far as the texture and chemical composition are concerned. At either end of the range of temperature, where the differences between the soil resistances are greatest, the mean probable error of using any one of these soils as standards, compared with the mean of all, is ± 1.2 per cent at 32°, while at 90° it is ± 1.4 per cent.

GLASS TEMPERATURE CELLS.

It was found that a simple solution of pure sodium chloride in distilled water does not have quite as great a temperature coefficient as the mean coefficient of these nine types of soil. It was found, however, that by the addition of alcohol the coefficient could be very materially changed, and in this way it was possible to make a temperature cell having a temperature coefficient practically equal to the mean coefficient of these nine types of soil.

The cell is made of a small glass tube about 3.5 millimeters in internal diameter, with platinum electrodes fused into each end, the cell being nearly filled with a salt solution. The electrodes are made of No. 25 platinum wire, twisted at one end to flat spirals which are parallel to each other and three inches apart. To prevent polarization, and to increase the sharpness of the minimum in the telephone, the spirals are covered with a coating of platinum black. The plating is done by passing a current of three or four volts E. M. F. through a solution of 1 part of platinic chloride and 0.008 part of lead acetate in 30 parts of water, using the platinum spiral as a negative electrode.

The salt solution in the cell covers both electrodes, and extends 4 or 5 millimeters above the upper one. Above the surface of the liquid there is an air space about 1 centimeter long to allow for the expansion and contraction of the solution. The salt solution finally adopted for use in the temperature cells contains 90 per cent of four-fifths normal pure sodium chloride solution and 10 per cent of commercial alcohol. Insulated, flexible wires are soldered to the electrodes at either end of the cells when they are ready to be standardized for use. When a fresh lot of solution has been used in the construction of a lot of new cells, several cells should be standardized at different temperatures in order to be certain that the solution has the proper temperature coefficient. If this is known to be correct, then the cells need only be standardized at a single temperature, from which the resistances of all other temperatures can be readily calculated.

In order to standardize the cells they are packed in pounded ice, in which they are kept at least half an hour after the resistance appears to be constant. The lead wires and ends of the electrodes going out from the cells must be thoroughly insulated, so that all of the current passes through the cell. The resistance of each cell is taken at least four or six times during this period to be sure that it is constant. This gives the resistance at 32° F. The cells are then placed in a large volume of water, or of linseed oil, at 40° F., and kept at that temperature for at least half an hour after the resistance of the cells appears to be constant. It is well to have the water or oil in a tin pail placed inside a large tub containing water. In this way the temperature can be maintained constant to within 0.1 or 0.2° C. by constant stirring and the addition of small quantities of either warm or cold water or oil. After the resistance of each of the cells has been taken a number of times at this temperature, the temperature of the bath is raised ten degrees Fahrenheit and the process repeated until the cells are standardized at every ten degrees between 32° and 100° F.

These cells have the great advantage that they can be easily and cheaply constructed in the laboratory and of any size desired. Cells have been used in this Division with the electrodes 1 inch, 3 inches, and 6 inches apart. For some special investigations in greenhouse soils cells were made with the electrodes 3 feet apart. In all such cases the diameter of the tube and the concentration of the solution should be so adjusted that the resistance of the cell will be about 2,000 ohms at 60° F. Considerable variation will occur, however, and each cell must be standardized at at least one temperature before being put into the soil.

The following tables give the actual resistance and the relative change of resistance of 6 temperature cells with temperature, selected at random from a lot which were made for this Division. The mean resistance of 21 of these cells for each 10 degrees in temperature was plotted and a smooth curve drawn through the points. From this curve, which is given in the accompanying figure, the resistance for each degree between 32° and 100° F. was determined, and is given in the first column of the table for calibrating temperature cells.

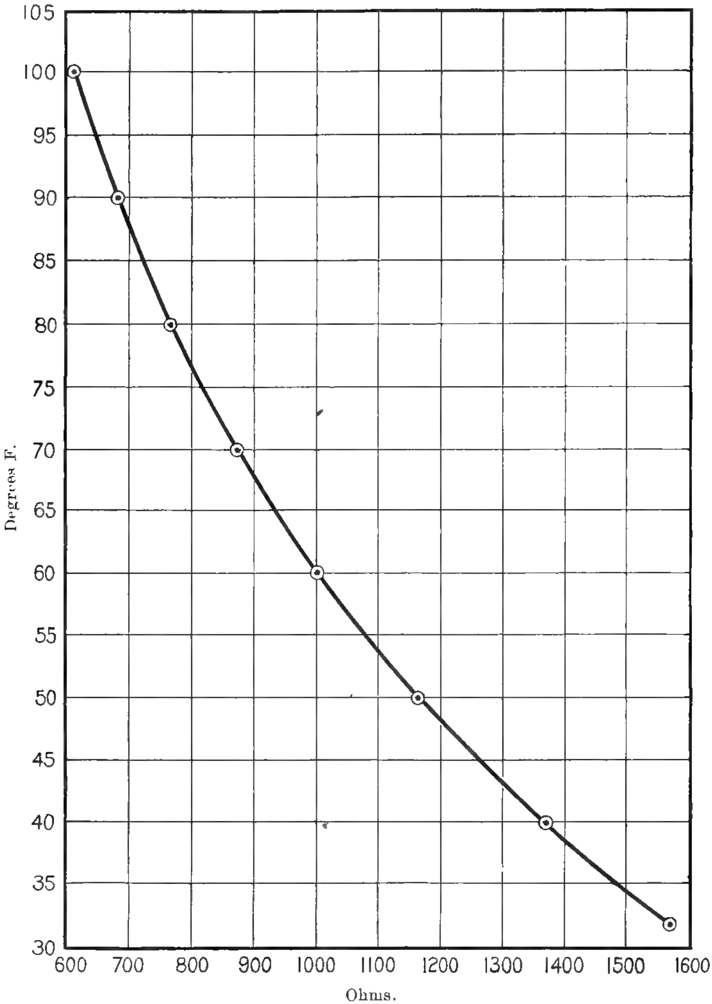

FIG. 1.—Relative change of resistance of a temperature cell with temperature.

Actual resistance of six temperature cells at different temperatures.

Cell No.	32°	40°	50°	60°	70°	80°	90°	100°
140	3, 030	2, 661	2, 257	1, 944	1, 695	1, 494	1, 328	1, 192
141	2, 750	2, 410	2, 045	1, 762	1, 536	1, 354	1, 202	1. 078
142	3, 240	2, 830	2, 400	2, 068	1, 801	1, 589	1, 412	1, 268
143	3, 264	2, 857	2, 426	2, 087	1, 819	1, 604	1, 427	1, 281
144	3, 384	2, 965	2, 512	2, 166	1, 883	1, 659	1, 474	1, 321
145	2, 736	2, 393	2, 030	1, 747	1, 524	1, 341	1, 191	1, 066

Relative resistances of six temperature cells at different temperatures.

Cell No.	32°	40°	50°	60°	70°	80°	90°	100°
140	1,559	1,369	1,161	1,000	872	769	683	613
141	1,561	1,368	1,161	1,000	871	768	682	612
142	1,566	1,369	1,161	1,000	871	768	683	613
143	1,563	1,369	1,162	1,000	871	768	683	614
144	1,563	1,369	1,160	1,000	869	766	680	610
145	1,562	1,371	1,162	1,000	872	768	682	611

The mean rate of change of resistance with temperature of twenty-one cells was found to be practically the same as the mean temperature coefficient of the nine types of soils already mentioned.

In order to construct correction cards for temperature calls a table has been prepared to facilitate the work. The first column of the table contains the mean rate of change of resistances with temperature, the resistance at 60° being taken to equal 1,000. The other columns are multiples of this. In order to construct a correction card for any cell by the use of this table the resistance of the cell at 60° F. should be known. If it can not conveniently be standardized at 60°, the reading at any other temperature can readily be reduced to the temperature of 60° by dividing the observed resistance by the resistance for that temperature in the first column of the table and multiplying the quotient by 1,000. For example, if the cell has a resistance of 1,913 ohms at 70°, the resistance at 60° will be $\frac{1,913}{870}1,000=2,197$ ohms. Having the resistance of the cell at 60°, the resistance at any other temperature can be readily determined from the table.

If the cell has a resistance of 2,197 ohms at 60°, the resistance at 40° would be found as follows: It will be noticed that 2,000 ohms at 60° is equal to 2,738 ohms at 40°. 1,000 ohms at 60° is equal to 1,369 ohms at 40°. 100 ohms would be one-tenth of this. The separate values are therefore found and added in the following way:

$$\begin{aligned} 2,000 &= 2,738 \\ 100 &= 137 \\ 90 &= 123 \\ 7 &= 9 \\ \hline 2,197 &= 3,007 \text{ at } 40^\circ \text{ F.} \end{aligned}$$

Table for calibrating temperature cells.

°F.	1,000.	2,000.	3,000.	4,000.	5,000.	6,000.	7,000.	8,000.	9,000.
32	1,564	3,128	4,692	6,256	7,820	9,384	10,948	12,512	14,076
33	1,538	3,076	4,614	6,152	7,690	9,228	10,766	12,304	13,842
34	1,512	3,024	4,536	6,048	7,560	9,072	10,584	12,096	13,608
35	1,487	2,974	4,461	5,948	7,435	8,922	10,409	11,896	13,383
36	1,463	2,926	4,389	5,852	7,315	8,778	10,241	11,704	13,167
37	1,439	2,878	4,317	5,756	7,195	8,634	10,073	11,512	12,951
38	1,415	2,830	4,245	5,660	7,075	8,490	9,905	11,320	12,735
39	1,392	2,784	4,176	5,568	6,960	8,352	9,744	11,136	12,528
40	1,369	2,738	4,107	5,476	6,845	8,214	9,583	10,952	12,321
41	1,346	2,692	4,038	5,384	6,730	8,076	9,422	10,768	12,114
42	1,323	2,646	3,969	5,292	6,615	7,938	9,261	10,584	11,907
43	1,301	2,602	3,903	5,204	6,505	7,806	9,107	10,408	11,709
44	1,279	2,558	3,837	5,116	6,395	7,674	8,953	10,232	11,511
45	1,258	2,516	3,774	5,032	6,290	7,548	8,806	10,064	11,322
46	1,237	2,474	3,711	4,948	6,185	7,422	8,659	9,896	11,133
47	1,217	2,434	3,651	4,868	6,085	7,302	8,519	9,736	10,953
48	1,198	2,396	3,594	4,792	5,990	7,188	8,386	9,584	10,782
49	1,179	2,358	3,537	4,716	5,895	7,074	8,253	9,432	10,611
50	1,161	2,322	3,483	4,644	5,805	6,966	8,127	9,288	10,449
51	1,143	2,286	3,429	4,572	5,715	6,858	8,001	9,144	10,287
52	1,126	2,252	3,378	4,504	5,630	6,756	7,882	9,008	10,134
53	1,109	2,218	3,327	4,436	5,545	6,654	7,763	8,872	9,981
54	1,092	2,184	3,276	4,368	5,460	6,552	7,644	8,736	9,828
55	1,076	2,152	3,228	4,304	5,380	6,456	7,532	8,608	9,684
56	1,060	2,120	3,180	4,240	5,300	6,360	7,420	8,480	9,540
57	1,045	2,090	3,135	4,180	5,225	6,270	7,315	8,360	9,405
58	1,030	2,060	3,090	4,120	5,150	6,180	7,210	8,240	9,270
59	1,015	2,030	3,045	4,060	5,075	6,090	7,105	8,120	9,135
60	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000
61	986	1,972	2,958	3,944	4,930	5,916	6,902	7,888	8,874
62	972	1,944	2,916	3,888	4,860	5,832	6,804	7,776	8,748
63	958	1,916	2,874	3,832	4,790	5,748	6,706	7,664	8,622
64	944	1,888	2,832	3,776	4,720	5,664	6,608	7,552	8,496
65	931	1,862	2,793	3,724	4,655	5,586	6,517	7,448	8,379
66	918	1,836	2,754	3,672	4,590	5,508	6,426	7,344	8,262
67	906	1,812	2,718	3,624	4,530	5,436	6,342	7,248	8,154
68	894	1,788	2,682	3,576	4,470	5,364	6,258	7,152	8,046
69	882	1,764	2,646	3,528	4,410	5,292	6,174	7,056	7,938
70	870	1,740	2,610	3,480	4,350	5,220	6,090	6,960	7,830
71	859	1,718	2,577	3,436	4,295	5,154	6,013	6,872	7,731
72	848	1,696	2,544	3,392	4,240	5,088	5,936	6,784	7,632
73	837	1,674	2,511	3,348	4,185	5,022	5,859	6,696	7,533
74	826	1,652	2,478	3,304	4,130	4,956	5,782	6,608	7,434
75	816	1,632	2,448	3,264	4,080	4,896	5,712	6,528	7,344
76	806	1,612	2,418	3,224	4,030	4,836	5,642	6,448	7,256
77	796	1,592	2,388	3,184	3,980	4,776	5,572	6,368	7,164
78	786	1,572	2,358	3,144	3,930	4,716	5,502	6,288	7,074
79	776	1,552	2,328	3,104	3,880	4,756	5,432	6,208	6,984
80	767	1,534	2,301	3,068	3,835	4,602	5,369	6,136	6,903
81	758	1,516	2,274	3,032	3,790	4,548	5,306	6,064	6,822
82	749	1,498	2,247	2,996	3,745	4,494	5,243	5,992	6,741
83	740	1,480	2,220	2,960	3,700	4,440	5,180	5,920	6,660
84	731	1,462	2,193	2,924	3,655	4,386	5,117	5,848	6,579
85	722	1,444	2,166	2,888	3,610	4,332	5,054	5,776	6,498
86	713	1,426	2,139	2,852	3,565	4,278	4,991	5,704	6,417
87	705	1,410	2,115	2,820	3,525	4,230	4,935	5,640	6,345
88	697	1,394	2,091	2,788	3,485	4,182	4,879	5,576	6,273
89	689	1,378	2,067	2,756	3,445	4,134	4,823	5,512	6,201
90	681	1,362	2,043	2,724	3,405	4,086	4,767	5,448	6,129
91	673	1,346	2,019	2,692	3,365	4,038	4,711	5,384	6,057
92	665	1,330	1,995	2,660	3,325	3,990	4,655	5,320	5,985
93	658	1,316	1,974	2,632	3,290	3,948	4,606	5,264	5,922
94	651	1,302	1,953	2,604	3,255	3,906	4,557	5,208	5,859
95	644	1,288	1,932	2,576	3,220	3,864	4,508	5,152	5,796
96	637	1,274	1,911	2,548	3,185	3,822	4,459	5,096	5,733
97	630	1,260	1,890	2,520	3,150	3,780	4,410	5,040	5,670
98	623	1,246	1,869	2,492	3,115	3,738	4,361	4,984	5,607
99	617	1,234	1,851	2,468	3,085	3,702	4,319	4,936	5,553
100	611	1,222	1,833	2,444	3,055	3,666	4,277	4,888	5,499

MEASURING THE ELECTRICAL RESISTANCE OF TEMPERATURE CELLS.

The electrical resistance of the cells can readily be measured by a slide meter bridge or box of coils found in nearly all physical and chemical laboratories, or which can readily be constructed, using the alternating current from a small induction coil, with a telephone in place of the galvanometer. The cells were, however, designed for and are very conveniently measured by the portable bridge box described in Bulletin No. 6 of this Division. This consists essentially of a rheostat, comparison coils and induction coil, and a watch-receiver telephone. One arm of the bridge contains a 1,000-ohm comparison coil, a second arm contains a 900-ohm coil and a 100-ohm coil in series, while a third arm contains the rheostat. The rheostat contains 102 10-ohm coils, while 4 1,000-ohm coils can be successively thrown in in series with the rheostat so that the resistances can be varied from 0 to 5,020 ohms. By means of a switch the 900-ohm comparison coil of the second arm of the bridge can be short-circuited so as to increase the range of the box tenfold. The wires from the temperature cell, buried in the soil at any distance from the observer, are connected to the proper binding posts and form the fourth arm of the bridge. More detailed instructions in regard to the construction and use of the bridge box may be obtained by consulting Bulletin No. 6 of this Division.

BURYING THE TEMPERATURE CELLS IN THE SOIL.

The cells may be buried in an excavation in the field to the proper depth and covered. It is better, however, to mount them on wooden blocks, lower the blocks to the proper depths in an auger hole, wedge them up so as to bed the cells in the soil and fill the hole with melted pitch.

The cells may be placed in an upright position in the soil and the temperature integrated for a depth corresponding to their own length, or they may be placed horizontally, when they will give the temperature of a depth corresponding to the thickness of the tube. They can be buried at any depth in the soil and remain there throughout the season, or they may be hung far up in a tree, or folded in a leaf, or attached to a stalk to get the temperature of a plant. It may be a mile away from the observing station. The only thing essential is that the resistance of the wires be negligible compared with the resistance of the cell.

For ordinary work it is best to have the resistance of the cell about 2,000 ohms at 60° F. Such a cell will vary 30 ohms in resistance between 59° and 60° F. If it has twice the resistance the variation will be twice as great.

The resistance of even a considerable length of wire may be rendered negligible by increasing the resistance in the cell. It is also possible to increase the sensitiveness of the cell by increasing the resistance.

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BULLETIN No. 8. S. 10.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF SOILS.

AN ELECTRICAL METHOD

OF

DETERMINING THE SOLUBLE SALT CONTENT OF SOILS,

WITH

SOME RESULTS OF INVESTIGATIONS ON THE EFFECT OF WATER AND SOLUBLE SALTS ON THE ELECTRICAL RESISTANCE OF SOILS.

BY

MILTON WHITNEY AND THOS. H. MEANS.

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1897.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS,
Washington, D. C., March 12, 1897.

SIR: I have the honor to transmit herewith a technical description of an electrical method of determining the soluble salt content of soils. I recommend that it be published as Bulletin No. 8 of this Division.

Respectfully,

MILTON WHITNEY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

TABLE OF CONTENTS.

ILLUSTRATIONS.

AN ELECTRICAL METHOD OF DETERMINING THE SOLUBLE SALT CONTENT OF SOILS.

A METHOD OF DETERMINING THE SOLUBLE SALT CONTENT OF SOILS.

A method of salt determination which would show readily and quickly the amount of soluble salt present in the soil and the fluctuations in the concentration of the soil moisture would obviously be of great value in studying the constitution of soils and the relation of the soils to crop production. An electrical method has been devised for this in connection with the electrical method of moisture determination described in Bulletin No. 6.

When a dry soil is moistened with water the minerals and salts in the soil dissolve to a certain extent, forming a salt solution. Some of the salts are so readily soluble that the amount in the soil is not sufficient to make a saturated solution. With the more difficultly soluble salts, however, the small quantities which are dissolved form a really saturated solution so far as these particular compounds are concerned. Any fluctuations in temperature or in the amount of moisture will disturb the equilibrium and induce more of these salts to go into solution or go out of solution as the case may be. Such solutions have certain physical properties, and among them the important property of electrical conductivity. The electrical conductivity depends upon the kind and upon the amount of salt in solution as well as upon the temperature. With the same salt in dilute solutions a solution has approximately twice the conductivity when the salt content is twice as great. With different salts the conductivity is roughly proportional to their molecular weight, or to some simple multiple of this.

As the electrical resistance of soils depends (1) upon the amount of salt solution (soil moisture), (2) upon the concentration of the solution, and (3) upon the temperature, it is possible to determine the soluble salt content of soils from the electrical resistance, provided the temperature and water content are known. On account of the difference in the molecular equivalents of different salts, however, it is necessary to express the quantity in equivalents of some simple salt, such as sodium chloride.

It was desired to perfect a method which would indicate the variations in the soluble salt content in the undisturbed soil of the field, but this has not yet been accomplished, although there is reason to believe it can eventually be done. A very simple and delicate method has, however, been devised for determining the soluble salt content of soils in samples taken from the field. The method consists essentially of mixing a known quantity of soil with a known proportion of pure water and determining the specific resistance. Then an equal weight of the same soil is mixed with a quantity of a dilute salt solution equal in volume to the pure water which had been mixed with the first quantity of soil. The specific resistance is again determined. This will be lower than before. The amount of salt added to the soil in solution is accurately known, as well as the effect it had on the resistance. From this data the quantity of salt originally present in the soil can readily be calculated in terms of the salt solution used.

DETERMINATION OF THE SPECIFIC RESISTANCE OF SOILS.

The specific resistance of soils as used in this bulletin is the resistance at 60° F. of one cubic centimeter of soil between parallel electrodes one centimeter apart. It is necessary, therefore, in comparing the specific resistance of different soils, or of different samples of the same soil, to give the weight of one cubic centimeter of the soil in order to show how much soil had been packed into this space, or to correct for this packing and reduce the volume in all cases to a unit weight. This may be done by a formula which will be given.

The specific resistance is determined in a hard rubber cell with metal electrodes. The cell is constructed in the following manner: Two heavy brass plates, each one-eighth inch thick, are ground together so that their faces are exactly plane. These are then firmly put together in the form of a cube with hard rubber sides and bottom, the rubber being about three-eighths inch thick. The interior of the cell should be as nearly as possible a cube with lineal dimensions of four centimeters. It must be accurately ground to these exact dimensions, the electrodes must be absolutely parallel, the cell must be water-tight, and the parts very substantially screwed together. The electrodes, as well as the screwheads, should be nickel plated and polished on the outside to prevent corrosion. Heavy copper wires should be soldered to each electrode, and bent so that they will dip into mercury cups as a convenient way of making the necessary connections for taking the resistance. It is convenient to have at least two of these cells, as the work can be done more quickly than with one.

Before use the weight of the cell should be taken, the distance between the electrodes should be very carefully measured, and the actual capacity of the cell should be determined either by measuring in water from a burette or by weighing the quantity of water the cell holds when full. It is essential that the sides be perfectly parallel and all the corners right angles. It is not essential that the inside be cubical. To obtain the specific resistance the observed resistance, when the cell is filled with soil, is multiplied by a constant factor for each cell. This factor is found by dividing the area of the electrodes ($a \times b$) by their distance apart (c). The whole operation would then be:

$$\text{Sp. res.} = R \frac{a\ b}{c}$$

It has been shown in Bulletin No. 6 that when the water content of soils change, either by the addition of water or by its loss through evaporation, that the actual amount of salt in solution as well as the concentration of the solution is liable to change. It is therefore essential in expressing the salt content of soils to state the water content also. In determining the salt content the method will depend somewhat upon the water content.

By far the easiest and quickest method of determining the soluble salt content is as follows: Measure 10 cubic centimeters of pure water from a burette into one of the hard rubber cells. The water for this as for all such work with soils must be very pure, having a specific resistance of at least 150,000 ohms. Dry soil is then poured into the cell until there is just enough to absorb all the water. The resistance is then measured, the temperature of the soil taken with a thermometer, and the weight of the cell and contents determined. The cell is then thoroughly cleaned and dried and 10 cubic centimeters of a *n/40* sodium chloride solution is measured into the cell from a burette. The cell is then put in the balance and soil is again poured in until the total weight of the cell and contents is the same as before. The resistance and temperature are again taken. This gives the resistance of a quantity of soil with the same water content, but with a known quantity of salt added to it. This quantity of salt lowers the resistance of the soil to a certain extent. From this a simple proportion will show how much sodium chloride the original soil should have contained to have had the resistance, or rather the conductivity which it was observed to have. The quantity of salt in the soil is thus expressed in terms of sodium chloride.

SOLUBLE SALT IN ONE GRAM OF SOIL.

After the resistance has been corrected for temperature, as will be described later, the weight of soluble salt in milligrams in one gram of soil in sodium chloride equivalents is found by the following formula:[1]

$$S = \frac{10s_1 R_1}{(R - R_1) W}$$

[1] Since for solutions in which the dissociation is complete the conductivity is proportional to the amount of the salt, we have

$$\frac{C}{C_1} = \frac{S_2}{S_2 + 10s_1},$$

where C and C_1 are the conductivities of the soil saturated with distilled water and salt solution, respectively, and S_2 the amount of soluble salt in the weight of soil used.

$$\text{But } C = \frac{1}{R} \text{ and } C_1 = \frac{1}{R_1}$$

$$\text{Therefore } \frac{R_1}{R} = \frac{S_2}{S_2 + 10s_1}$$

Solving for S_2

$$S_2 (R_1 - R) + R_1\, 10s_1 = O$$

$$\text{or } S_2 = \frac{R_1\, 10s_1}{R - R_1}$$

Since there are W grams of soil used the amount of salt in one gram is

$$S = \frac{S_2}{W} = \frac{10s_1 R_1}{(R - R_1) W}$$

where S = milligrams salt in one gram of soil; s_1 = milligrams salt in 1cc. salt solution; R = resistance of soil saturated with distilled water; R_1 = resistance of same quantity of soil saturated with same quantity of salt solution; W = weight of soil in the cell in grams.

If it is desired to determine the soluble salt content of soil with various percentages of water, short of saturation, the method must be somewhat different and it requires a much larger quantity of soil.

A sufficient quantity of soil, the amount depending upon the range of the investigation, is thoroughly air dried and if at all lumpy is passed through a mill to break down the lumps. It is then well mixed. Equal portions of 500 or 1,000 grams each are weighed out in beakers, two portions for each per cent of moisture it is desired to have in the soil. To one portion of soil a certain percentage of pure water is added, while to a second portion an equal quantity of a dilute sodium chloride solution, preferably *n/40* or *n/20*, is added. The amount of salt added may either vary with the water or, what is preferable, remain a constant quantity irrespective of the amount of water added. It is usual in this Division to take a quantity of a *n/20*-salt solution equal to 4 per cent of the dry weight of the soil. This is measured into a beaker from a burette and pure water is added up to the full percentage of moisture which it is desired to add to the soil. One portion only should be moistened at a time to prevent loss by evaporation, but the method of subsequent procedure is precisely the same in both cases.

The moist soil is thoroughly mixed with a Dover's egg-beater, securely fastened to a shelf or table, to distribute the water uniformly throughout the mass of soil. The soil must not be mixed with the hands, as the salts from the hands are liable to vitiate the results, especially in a warm room where the hands are perspiring freely. The soil should be put in a round-bottom bowl or in a heavy glass cover, such as is used in the laboratory to protect apparatus and specimens from dust. With clay soils especially it is well to empty the soil out of the bowl and pour it back again once to insure thorough mixing of the water or solution throughout the mass of soil.

The well-mixed soil is emptied on to a piece of clean oilcloth. One of the hard rubber cells is then filled by putting in small quantities of the soil and pressing it into the corners and down into the cell as firmly as possible with the thumbs. The soil is struck off even with the top of the cell with a spatula. The cell is then placed with its wire electrodes dipping into mercury cups and the resistance taken with an alternating current. The cell and contents are then quickly weighed and the temperature of the soil taken by making a hole in the soil with a pointed instrument and inserting the bulb of a thermometer. After remaining a few moments the temperature is taken. A portion of the soil is then immediately emptied into a flat porcelain or aluminium dish, quickly weighed on a chemical balance, dried for fifteen or twenty hours at a temperature of 110° C., and the true moisture content obtained from the loss of weight. Usually three or four determinations are made of the same lot of moist soil and the mean of all taken to find the specific resistance.

CORRECTION FOR TEMPERATURE.

The resistances are all corrected for temperature by reducing them to a uniform temperature of 60° F. by the use of the table at the end of this bulletin. Wherever resistances or conductivities are referred to in this bulletin it will be hereafter understood that they have been corrected for temperature before any further use is made of them. This is the first thing to do after the resistances have been taken, as they can not be compared until this is done.

CORRECTION FOR PACKING.

As it is impossible to pack just the same amount of soil in the cell, in duplicate determinations with the same or with different soils it is usually necessary, in order to compare the results, to correct them all for the difference in packing. This can readily be done by the use of the formula:

$$R_2=\frac{W^2R}{W_1^2},$$

where R_2 = resistance if the cell contained a unit weight of soil; R = observed resistance; W = actual weight of soil contained in cell; W_1 = unit weight of soil (usually 100 grams for a cell of the dimensions given above).

SALT ADDED TO ONE CUBIC CENTIMETER OF SOIL.

The salt added to the soil by the salt solution lowers the resistance of the soil considerably. The actual amount of salt added to one cubic centimeter of soil in the cell is calculated by the following formula:

$$S_1=\frac{W}{V}p_1\ s_1,$$

where S_1 = milligrams of salt added to one cubic centimeter of soil by the salt solution used; s_1 = milligrams of salt in one cubic centimeter of salt solution; W = grams of soil in cell; V = volume of cell; p_1 = per cent of salt solution of given strength added to the soil.

SOLUBLE SALT IN ONE CUBIC CENTIMETER OF SOIL.

Having determined the amount of salt added to the soil by the salt solution and the extent to which it has lowered the resistance, the amount of salt originally present in the soil may be calculated by a simple proportion in terms of sodium chloride. The proportion is expressed in the following formula:

$$S_2=\frac{S_1\ R_1}{R-R_1},$$

where S_2 = milligrams of salt in one cubic centimeter of natural soil in terms of sodium chloride; S_1 = milligrams of salt added to one cubic centimeter of soil by means of the salt solution; R = resistance of natural soil; R_1 = resistance of the soil to which salt solution has been added.

SALT IN ONE CUBIC CENTIMETER OF SOIL MOISTURE.

Knowing the weight of soluble salts in sodium chloride equivalents contained in one cubic centimeter of soil, it is a simple matter to calculate the amount of salt in one cubic centimeter of soil moisture which will give the concentration of the salt solution in the soil. This is done by the formula:

$$s = \frac{S}{W_1\,p},$$

where s = milligrams of salt in one cubic centimeter of soil moisture expressed in terms of sodium chloride; S = milligrams of salt in one cubic centimeter of natural soil; W_1 = weight of one cubic centimeter of soil calculated from the total weight of soil and volume of the cell; p = the per cent of water in the soil. One cubic centimeter of *n/20* sodium chloride solution contains 2.918 milligrams of salt.

SALT CONTENT OF SOILS OF SAME TEXTURE.

When samples of soils of the same texture are to be used for a series of investigations the method can be shortened considerably as it is only necessary to accurately determine the salt content once, together with the specific resistance. Thereafter it will only be necessary to determine the specific resistance of the soils and, if the soils are saturated with water, or, when short of saturation if a correction is made for packing and the water content is the same, the amount of salt can be calculated by the formula:

$$S_a = \frac{R\,S_2}{R_a},$$

where S_a = salt content to be determined; R = specific resistance with known salt content; R_a = specific resistance with unknown salt content; S_2 = salt content corresponding to specific resistance R.

DEFINITION OF TERM "SODIUM CHLORIDE EQUIVALENT."

It has been stated that the electrical molecular conductivity of different salts in solution is roughly proportional to their molecular weight or some simple multiple of the same. As it is not possible to distinguish the different salts as they occur mixed in the soil moisture by their electrical properties, it is necessary to estimate the total quantity of salts present in solution in terms of some well-known salt easily obtainable in a pure state and which will keep in an ordinary aqueous solution without deterioration or change. For this purpose sodium chloride has been selected as the standard of measurement in the investigations in this Division. The quantity of other salts in solution is expressed in terms of sodium chloride equivalents. A sodium chloride equivalent may be defined as the quantity of a salt which has the same electrical conductivity as a unit weight of sodium chloride when dissolved and diluted to the same volume.

Owing to the difference in molecular weight of different salts, in the number of ions formed through dissociation, and in the ionic velocities this quantity will not have a constant value. The following results, calculated from the investigations of Kohlrausch, give the approximate

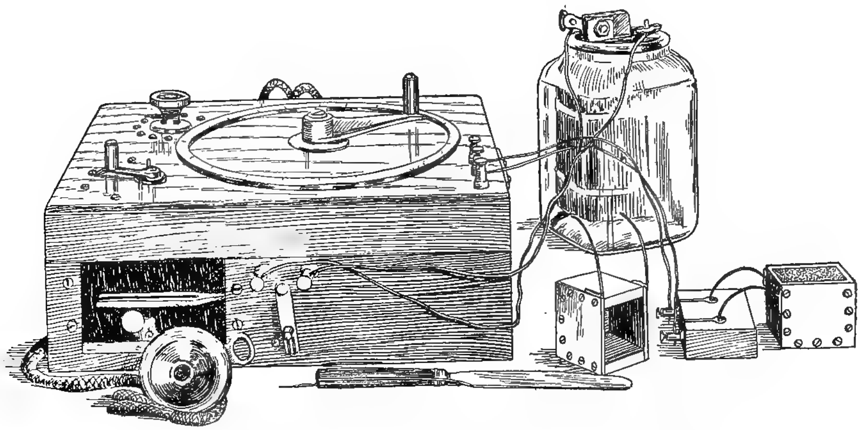

FIG. 1.—Bridge box with cells used in determining the soluble salt content.

relative weights of some of the most common salts which, under the above conditions, have a conductivity equal to sodium chloride:

$NaCl$	1
KCl	1.07
K_2SO_4	1.21
KNO_3	1.49
$NaNO_3$	1.55

THE MEASUREMENT OF THE ELECTRICAL RESISTANCE.

The electrical resistance is measured by the Wheatstone bridge method, with an alternating current to prevent polarization and a telephone in place of a galvanometer. The measurements may be made with a slide-meter bridge or a suitable box of coils. The portable bridge box, described in Bulletin No. 6, is a very convenient form for laboratory or field use. The construction and use of the box is described in the bulletin. The bridge box, with one of the hard rubber cells in position, with electrodes dipping into mercury cups as in the actual salt determinations, is shown in the accompanying figure (1).

SOLUBLE SALT CONTENT OF SEVERAL SOILS.

The accompanying table gives the soluble salt content of a number of soils determined by this method, both when the soils are saturated with water and with different percentages of water in some of them:

Soluble salt content of soils saturated with water.

[In sodium chloride equivalents.]

No. of samples.	Kind of soil.	Formation.	Salt content. In 100 grams.	Salt content. In one acre.*
			Mg.	*Lbs.*
3	Bright tobacco, North Carolina.	....	4.27	171
1	Red land, South Carolina...	Lafayette.............	4.95	198
24	Truck, Maryland	Columbia	5.84	234
12	Dark tobacco, Virginia	Gabbro, gneiss.........	6.76	270
1	Corn, wheat, Maryland.....	Gabbro	12.75	510
1	Corn, Maryland.............	Trenton limestone....	14.04	562
6	Loess, Nebraska............	Loess..................	15.69	628
19	Grass, Maryland, Virginia..	Trenton limestone....	16.44	650
1	Sea-island cotton, South Carolina.	....	22.36	894
1	Wheat, Maryland...........	Chesapeake...........	25.33	1,013
1	Wheat, grass, Maryland....	.....do	27.46	1,098
1	Tobacco, Pennsylvania.....	Shaly limestone	31.30	1,252
15	Plains soil, Kansas, Nebraska.	....	34.87	1,395
1	Blue grass, Kentucky	Trenton limestone....	37.04	1,482
1	Loess, Illinois	Loess..................	45.28	1,811
1	Plains marl, Nebraska......	Plains marl...........	45.71	1,828
1	Wheat, Maryland...........	Trenton limestone....	59.69	2,388
1	Grass, Maryland............	.....do	62.23	2,489
1	Stiff clay, Virginia..........	.....do	83.56	3,342

* The soil is assumed to weigh 4,000,000 pounds per acre, one foot deep.

Specific resistance and soluble salt content of soils short of saturation.

Water.	Weight 1 cc. soil.	Specific resistance.	Salt in 100 g. soil.	Salt in 10 cc. soil moisture.
BRIGHT-TOBACCO LAND, NORTH CAROLINA.				
Per cent.	*Grams.*	*Ohms.*	*Mg.*	*Mg.*
18	1.54	34,260	3.03	1.68
15	1.54	40,300	3.20	2.13
12	1.54	57,430	3.17	2.62
9	1.54	111,830	3.77	4.19
7	1.54	191,400	3.21	4.59
"HEAVY" LOAM, MARYLAND.				
21	1.54	9,790	11.73	5.58
18	1.54	12,260	12.88	7.16
15	1.54	19,655	11.08	9.23
12	1.54	33,930	9.87	8.22
9	1.54	73,968	11.16	12.40
LOAM, MARYLAND.				
21	1.54	6,854	12.54	5.97
18	1.54	7,758	14.53	8.07
15	1.54	9,688	17.41	11.61
12	1.54	13,990	19.47	16.23
9	1.54	22,914	28.65	31.84

Specific resistance and soluble salt content of soils short of saturation—Continued.

Water.	Weight 1 cc. soil.	Specific resistance.	Salt in 100 g. soil.	Salt in 10 cc. soil moisture.
SEA-ISLAND SOIL, SOUTH CAROLINA.				
Per cent.	*Grams.*	*Ohms.*	*Mg.*	*Mg.*
15	1. 38	4, 360	37. 94	25. 29
12	1. 36	5, 600	35. 57	29. 64
9	1. 34	8, 050	29. 92	33. 25
6	1. 33	21, 000	24. 01	40. 01
LOESS, ILLINOIS.				
18	1. 47	4, 631	30. 49	17. 00
15	1. 45	5, 478	31. 66	21. 10
12	1. 42	6, 399	36. 99	30. 70
9	1. 40	8, 009	42. 97	47. 60
7	1. 39	10, 051	60. 12	86. 00

As a rule, the amount of soluble salt is greatest in the heavy clay soils, but this is not always so. The sandy bright-tobacco and truck soils have the least, while the heavy clay, gabbro, and gneiss soils of Virginia, the so-called "worn-out tobacco lands," have hardly more. Some of the other soils have eight or ten times as much. Where the different percentages of water are added to the soils, the concentration of the solution decreases with the increase of water. In one case the amount of salts in solution increases with the amount of water, in two cases it decreases, while with the remainder of the soils it is fairly constant.

These investigations were all made with air-dried laboratory samples of subsoil which had been collected under various conditions of climate, season of the year, and cropping. It would be of great value to make a systematic study of the soluble salt content of representative soils at frequent intervals throughout the year, with special reference to the character of the season and cropping and at several stated depths below the surface.

One very important matter which has been brought to light during the course of the investigations is that very slight changes of conditions have a very marked influence on the solubility of the soil constituents. Thus, if the soil is dried at 110° C., as in the ordinary moisture determination, the amount of salts which will go into solution in pure water is frequently increased 100 per cent.

In considering the nature of the soluble salts in the soil it must be remembered that the capillary spaces in the soils are so small, and the films of moisture around the grains in a soil short of saturation are so extremely thin, that the fluid loses the properties of a liquid in mass. The most striking property of the soil moisture, as considered in the light of a salt solution, is that part of the salts of the soil may be in solution and yet not be readily washed out.

Some quite dry soil was put into a cell with metal electrodes and leached by a constant stream of pure water. The accompanying table shows that the resistance fell enormously on saturating the soil, but on continuing the flow the leachable salts were quickly carried out, the resistance increasing until, with these two soils, it was five times as much as when first saturated, when it remained constant. Approximately four-fifths of the salts were leachable and one fifth were nonleachable, and while they were in solution and were dissociated in the soil they could not readily be washed out.

Experiments on leaching soils.

A.		B.	
Time.	Resistance.	Time.	Resistance.
Min.	*Ohms.*	*Min.*	*Ohms.*
Initial.	77,000	Initial.	35,000
0	500	4	1,600
3	670	17	410
20	1,150	20	600
28	1,840	28	1,050
45	1,970	46	1,400
85	2,390	85	1,950
121	2,370	122	1,990
194	2,450	194	1,780
217	2,690	217	2,200
239	2,690	239	2,270
265	2,650	265	2,270

Soils have what may be called a solution constant; that is, after all the readily soluble salts have been removed the other constituents of the soil continue to be slowly dissolved for a very long time. It is a very difficult thing, therefore, to determine the solubility of a soil either in water or other solvents.

A quantity of a soil was mixed with twice its volume of distilled water and well shaken. Then half of the solution was poured off and replaced by an equal quantity of distilled water. This was repeated, the resistance of each portion being taken as it was poured off. If no dissolving action had been taking place, the process would have resulted in a simple dilution of the soluble salt already present, and the resistance of each portion would have been approximately twice that of the preceding portion. The following results indicate the continuous solution of the soil salts:

	Ohms.
Initial resistance	1,185
After first replacement	1,545
After second replacement	2,130
After third replacement	2,830
After fourth replacement	2,830
After fifth replacement	3,420
After sixth replacement	3,920
After seventh replacement	4,900
After eighth replacement	5,400
After ninth replacement	8,000
After standing twenty-four hours	3,250

Even with purified quartz sand (glass sand) which had been digested with acids and alkalies and thoroughly washed there was a slow solution. To a quantity of the sand was added a small amount of pure sodium chloride and some pure water in a flask of Jena glass. This was shaken several times a day and the resistance of the solution determined daily with the following results:

	Ohms.
Resistance, initial	1,587
Resistance after three days	1,167
Resistance after six days	1,159
Resistance after nine days	1,153
Resistance after fourteen days	1,143
Resistance after seventeen days	1,112
Resistance after twenty days	1,089
Resistance after twenty-three days	1,090

Some of the same solution in a similar flask without the sand showed practically no change during this time. Natural soils show the same gradual increase in solubility, except that in a few cases the resistance has been noticed to go up for a few days as though salts were going out of solution, usually to fall again on longer standing.

In such digestion experiments great care must be taken to secure extremely insoluble glass. The ordinary Bohemian glassware, such as is used for measuring flasks in chemical laboratories, is liable to be quite soluble and entirely unsuited to this work. Thus some flasks which had been thoroughly steamed and cleaned with acids and alkalies and washed were filled with water having a specific resistance of 148,000 ohms. The water was then immediately emptied from the flasks and the resistance taken. It was then replaced and the flasks heated for three hours in a steam bath. They were then allowed to stand forty hours, when the resistance was again taken, with the following results:

No. of flask.	Resistance.	
	Initial.	After steaming.
(Water used)	148,000	....
1	110,000	13,000
2	82,900	1,020
3	77,000	15,000
4	119,000	8,450
5	115,000	1,550
6	93,000	1,420
7	100,000	3,100
8	66,300	1,650

The resistance of a *n/300* sodium-chloride solution is about 1,500 ohms.

On the other hand, common glass bottles are often highly insoluble, and high-grade water even improves on standing in them. It is necessary, before any work on the solubility of soils is undertaken, to actually test the solubility of all the glass used.

If a convenient method is devised for determining the soluble salt content of soils in the field by electrodes buried at different depths, as is now done in the case of water, it will undoubtedly show that the soluble salts are constantly fluctuating with changing conditions, sometimes more salts going into and at other times more salts going out of solution. It is needless to say that such a line of investigation, with a method which can be relied upon to detect variations of a thousandth of a milligram of soluble salt in a gram of soil, is of the utmost importance in studying the fundamental problems of cultivation, fertilization, and rotation of crops.

THE INFLUENCE OF WATER AND OF SOLUBLE SALTS ON THE ELECTRICAL RESISTANCE OF SOILS.

Investigations along these lines throw an important light upon the chemical and physical constitution of soils. Furthermore, it was necessary to thoroughly investigate the influence of water and salts on soils in connection with the method of moisture determination described in Bulletin No. 6.

INFLUENCE OF MOISTURE ON THE ELECTRICAL RESISTANCE OF NATURAL SOILS.

The method of procedure is the same as for salt determinations already described, except that no salt solution is used. Equal quantities of the soil are thoroughly mixed with 5, 6, and so on, up to 25 or 35 per cent by weight of water. The specific resistance is determined in the hard rubber cell, and when the actual moisture determination and corrections for packing and temperature are made the results are plotted on cross-section paper of large scale and a curve drawn through the points of observation. The resistance for each whole per cent of water is then picked out from this curve.

As the specific resistance of the different soils varied greatly, owing to the difference in salt content, they were all reduced to some common basis. With soils in which the moisture naturally varies in the field from 5 to 20 per cent the resistance with 10 per cent is taken to equal 1,000, and all the other resistances are reduced in the same proportion. With soils in which the moisture ranges from 10 to 25 per cent the resistance with 15 per cent is taken to equal 1,000. These reduced readings give the rate of change of resistance with changing water, and the curve is called a ratio curve.

The accompanying tables give the specific resistance, specific conductivity, and rate of change of resistance with changing moisture of a number of soils:

Specific resistance and conductivity of soils.

[Conductivity multiplied by 10,000.]

Per cent moisture.	Truck land.		Sea-island cotton land.		Bright tobacco land.		Loess.	
	Resistance.	Conductivity.	Resistance.	Conductivity.	Resistance.	Conductivity.	Resistance.	Conductivity.
15	....	....	4, 367	2. 291	8, 660	1. 155	5, 478	1. 826
14	....	....	4, 731	2. 114	9, 510	1. 052	5, 768	1. 734
13	4, 060	2. 463	5, 145	1. 944	11, 640	0. 859	6, 059	1. 650
12	4, 210	2. 375	5, 602	1. 785	12, 190	0. 821	6, 399	1. 563
11	4, 480	2. 232	6, 183	1. 617	14, 600	0. 685	6, 764	1. 478
10	5, 150	1. 942	6, 971	1. 435	18, 030	0. 555	7, 284	1. 373
9	6, 600	1. 515	8, 052	1. 242	22, 700	0. 441	8, 009	1. 249
8	8, 800	1. 136	9, 752	1. 026	30, 220	0. 331	8, 943	1. 119
7	12, 200	0. 820	12, 680	0. 789	41, 310	0. 242	10, 051	0. 995
6	16, 200	0. 617	21, 000	0. 476	....	....	11, 338	0. 882

Ratio of change of resistance with changing moisture content.

Per cent moisture.	Truck land.	Sea-island cotton.	Bright tobacco.	Loess.
16	....	571	....	713
15	....	621	627	752
14	....	674	679	791
13	788	734	738	832
12	818	799	804	879
11	870	882	887	928
10	1,000	1,000	1,000	1,000
9	1,252	1,148	1,155	1,097
8	1,709	1,391	1,399	1,227
7	2,369	1,806	1,820	1,380
6	3,147	2,994	3,013	1,557

Specific resistance, conductivity, and ratio of two loam soils from Maryland.

[Conductivity multiplied by 10,000.]

Per cent moisture.	Loam.		Heavy loam.		Ratio.	
	Resistance.	Conductivity.	Resistance.	Conductivity.	Loam.	Heavy loam.
20	7,261	1.377	10,790	0.927	726	560
19	7,595	1.317	11,620	0.860	760	603
18	8,090	1.236	12,660	0.790	800	657
17	8,549	1.170	14,010	0.714	855	727
16	9,170	1.090	16,140	0.620	917	838
15	10,000	1.000	19,250	0.518	1,000	1,000
14	11,100	0.900	23,240	0.430	1,110	1,207
13	12,570	0.796	28,531	0.350	1,257	1,482
12	14,440	0.693	35,010	0.285	1,444	1,819
11	16,720	0.598	42,940	0.233	1,671	2,230
10	19,790	0.505	55,400	0.180	1,979	2,877

It will be seen from the tables that the resistance varies greatly with the amount of moisture. It is upon this great change in resistance that the method for the determination of the water content of soils, described in Bulletin No. 6, is based. Thus, between 6 and 12 per cent of moisture the resistance of the truck land varied about 12,000 ohms, while the measuring apparatus is accurate to at least 10 ohms below 5,000 and 100 ohms between 5,000 and 50,000. The specific resistance of different soils varies greatly with the same percentage of moisture, partly due to the difference in salt content and partly, as will be shown, to the difference in texture of the soils.

The ratio curve shows that water does not have the same influence on the resistance of all soils. It requires from 1 to 3 per cent more water to produce the same change in the resistance of some soils than in others. Part of this is due to the difference in the amount of salt in solution with the different per cents of water, but this difference in the solubility of soils does not account for it all. When the actual resistances are plotted they make smooth curves, and when the relative resistances are plotted it is seen that the curves for different soils while regular and approximately of the same order have a different slope. They agree in the main with an hyperbolic curve except that they are more or less rotated. This difference in slope seems to be characteristic of the different soils.

The conductivity corresponding to the hyperbola curve gives a straight line when plotted. The conductivities of these soils give ap-

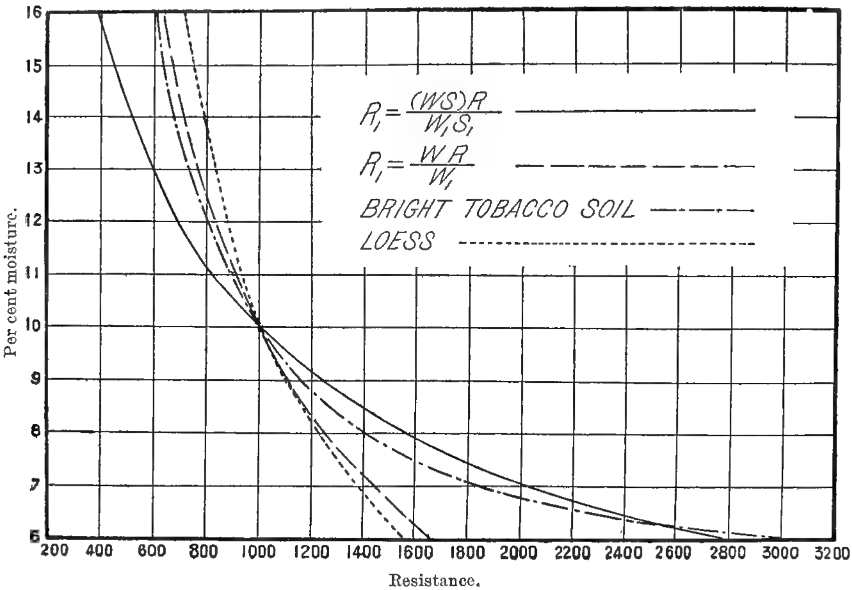

FIG. 2.—Resistance-moisture curves of loess and bright tobacco soils.

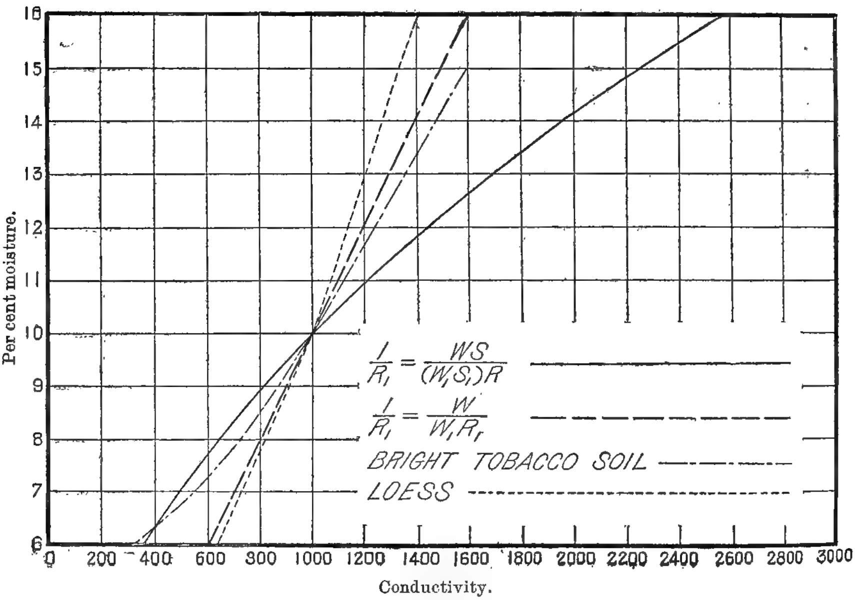

FIG. 3.—Conductivity-moisture curves of loess and bright tobacco soils.

proximately straight lines with different inclinations as compared with the hyperbola. This makes it easier in some respects to deal with the conductivities than with the resistances, as each percentage of water has about the same value in conductivity units whether the soil is wet

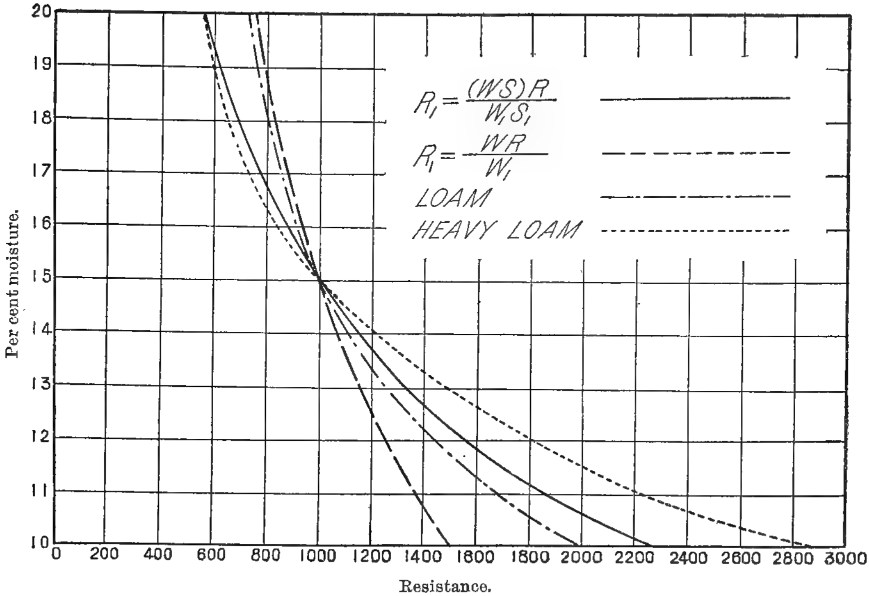

FIG. 4.—Resistance-moisture curves of two loams from Davidsonville, Md.

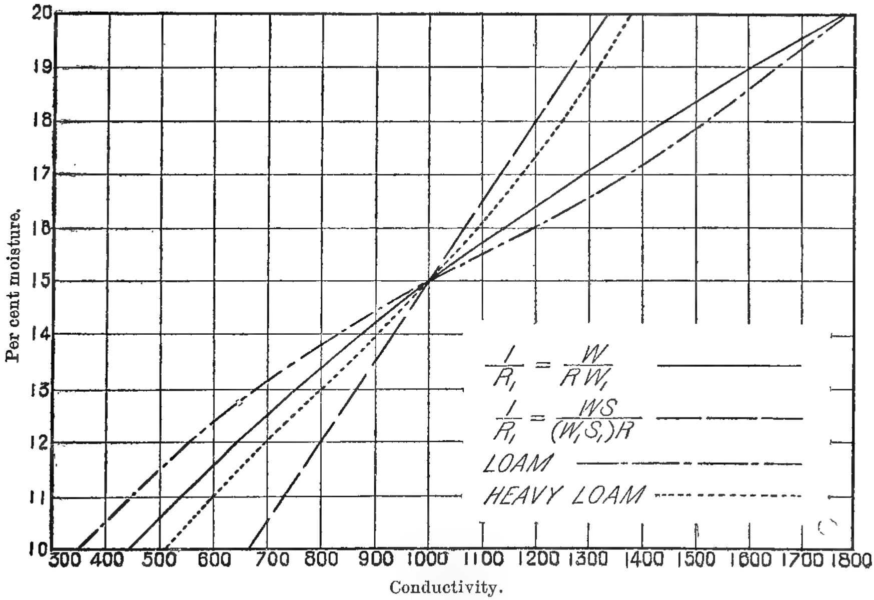

FIG. 5.—Conductivity-moisture curves of two loams from Davidsonville, Md.

or dry, while it has very different values in resistance. A table of reciprocals for calculating the conductivity from the resistance is given in Bulletin No. 6.

The accompanying figures (2, 3, 4, 5) show the conductivities of these different soils, together with the reciprocals of two hyperbolic curves. If the curves were the same as the hyperbola $R_{/} = \frac{W\,R}{W_{/}}$ then the conductivity would vary directly with the amount of moisture. If it followed the other hyperbola the resistance would vary as the square of the moisture content.

RESISTANCE OF SALT SOLUTION ABSORBED IN PURE QUARTZ SAND.

In order to study further in regard to the electrical properties of soils, an artificial soil was made up of pure quartz sand and salt solutions of various strengths. The sand (glass sand) was thoroughly purified by digesting in hydrochloric acid, carbonate of soda, and by repeatedly washing with pure water until the specific resistance of the wash water was at least 200,000 ohms. Equal quantities of this sand were then thoroughly mixed with 5, 6, 7, and up to 19 per cent of different strength salt solutions, and the specific resistance of the moist sand was determined by use of the hard-rubber cell. The results are given in the accompanying table.

Resistance of salt solution absorbed in pure quartz sand.

Per cent moisture.	Specific resistance.				Ratio 10 per cent=1,000.							
	$\frac{n}{20}K_2SO_4$.	$\frac{n}{10}$NaCl.	$\frac{n}{20}$NaCl.	$\frac{n}{40}$NaCl.	$\frac{n}{20}K_2SO_4$.	$\frac{n}{10}$NaCl.	$\frac{n}{20}$NaCl.	$\frac{n}{40}$NaCl.	Mean.	$R_{,}=\frac{(WS)R}{W_{,}S_{,}}$.*	Salt constant.	$R_{,}=\frac{WR}{W_{,}}$.†
19	1,079	1,058	2,075	4,150	260	264	277	266	267	277	507	526
18	1,232	1,120	2,303	4,565	297	280	307	292	294	309	529	555
17	1,398	1,245	2,614	5,063	337	311	349	324	330	346	561	588
16	1,577	1,432	3,008	5,644	380	357	402	362	375	390	600	625
15	1,784	1,681	3,485	6,349	430	420	465	406	430	444	645	666
14	2,075	1,992	4,046	7,262	500	497	540	465	500	510	700	714
13	2,378	2,365	4,689	8,632	573	591	626	553	586	592	762	769
12	2,768	2,802	5,437	10,458	667	700	726	664	689	695	827	833
11	3,349	3,319	6,349	12,740	807	829	847	816	825	826	907	909
10	4,150	4,000	7,491	15,604	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
9	5,329	5,023	9,378	18,675	1,284	1,254	1,252	1,200	1,247	1,235	1,122	1,111
8	7,001	6,494	12,180	24,070	1,687	1,622	1,626	1,540	1,619	1,563	1,295	1,250
7	9,171	8,632	16,600	32,702	2,210	2,155	2,216	2,100	2,170	2,041	1,519	1,444
6	12,313	11,740	21,580	45,650	2,967	2,933	2,881	2,920	2,925	2,777	1,755	1,666
5	17,015	17,110	31,540	65,196	4,100	4,275	4,210	4,180	4,191	4,000	2,095	2,000

* The salt varies directly as the water. The resistance agrees with the curve represented by the equation $R_{,}=\frac{(WS)R}{W_{,}S_{,}}$, where R=resistance with unit quantity of water; $R_{,}$=resistance with any other quantity of water; W=unit quantity of water (10 per cent in this case); S=salt with unit quantity of water; $S_{,}$=salt content with any other quantity of water.

† The salt is constant, while the water alone varies. The resistance agrees with the hyperbolic curve and the equation would be $R_{,}=\frac{WR}{W_{,}}$.

It is seen that the resistance is very nearly inversely proportional to the amount of salt. The resistance of the *n/20* solution is very nearly half the resistance of the *n/40* and approximately twice that of the *n/10*, although here the effect of the greater dissociation in the dilute solutions is apparent. The resistance of the *n/20* potassium sulphate solution is about equal to the *n/10* sodium chloride solution. This is because the sulphate ion carries a double electric charge, so that the solution has twice the conductivity of a solution of sodium chloride of the same number of salt equivalents. From the second part of the table it is seen that notwithstanding the differences in actual resistance, the rate of change is about the same for the different salts and the different strengths of salt solutions. This rate of change seems to be independent of the nature of the salt or of the strength of the solution in the case of sodium chloride, potassium sulphate, potassium nitrate, and acid potassium phosphate. The mean results show that when the amount of the salt solution is double and there is twice as much water and twice as much salt present, the resistance is about one-fourth. If the water alone is doubled, while the salt remains constant, the resistance will be one-half. On the other hand, when there is one-half as much solution, so that there is half as much water and half as much salt, the resistance is four times as great, while if there is half as much water and the same quantity of salt the resistance is twice as great. Where the salt and the water change in the same proportion the resistances when plotted agree with one hyperbolic curve and the resistance, or the water, or the salt can be calculated for any part of the curve if any two of the values are known. Where the salt is constant and the water alone changes, the resistance agrees with another hyperbola and the conductivities would form a straight line. This may be taken as the basis in studying the relation of water and of salts to the electrical resistance of soils, and the departures from these simple laws will indicate other properties of soils which will be valuable in working out the chemical and physical constitution of the soils.

It is plain, from a consideration of the principles of the electrical properties of solutions, that if a quantity of a salt solution was put into a hard rubber cell with parallel electrodes and diluted with pure water that the resistance would not be affected except as a result of further dissociation. If a small quantity of salt solution is added to the quartz sand, however, and is then diluted, the resistance continues to decrease in a regular manner until the soil is completely saturated. This shows at once a property of a soil which influences the electrical resistance of solutions, and the investigation of which has already thrown an important light upon the constitution of soils.

To study this matter further 10 cc. of a salt solution were put into the hard rubber cell. If successive portions of pure water had been added to this solution the effect on the resistance would not have been noticeable, except for the slight change due to increased dissociation with the greater dilution. Purified quartz sand, however, was put into the solution in portions of 10 grams each. The resistance immediately began to rise. With 30 grams of sand the solution was just absorbed, the sand being completely saturated. The resistance at this point was 50 per cent greater than for the solution without the sand. The successive portions of 10 grams of soil added beyond this point increased the resistance, each portion having just the same effect as any other. The effect was cumulative, so that the total resistance after 220 grams of soil had been added was about fifteen times greater than the resistance of the solution before any sand had been added. At this time there was 4.5 per cent of water in the sand. These results are shown in the accompanying table. Ten centimeters of solution were used in each case and were thoroughly mixed with different quantities of sand, as shown in the second column. The third column shows the per cent of moisture, the fourth column shows the actual resistance, the next column shows the ratio, taking the resistance of the solution as one, while the last column gives the increase in resistance for each 10 grams of sand added.

Influence of quartz sand on the electrical resistance of a salt solution.

Solution.	Sand.	Moisture.	Actual resistance.	Ratio.	Differences. *
cc.	*Grams.*	*Per cent.*	*Ohms.*		
10	0	....	171	1	0
10	30	33.3	259	1.51	0.51
10	40	25.0	350	2.05	0.54
10	60	16.7	580	3.39	0.67
10	80	12.5	795	4.65	0.63
10	1,00	10.0	933	5.46	0.41
10	1,20	8.3	1,292	7.55	0.54
10	1,40	7.1	1,477	8.63	0.54
10	1,80	5.5	1,910	11.17	0.64
10	2,20	4.5	2,530	14.91	0.94

* For each 10 grams of sand added beyond 30.

When these results are plotted, using the resistance for the ordinates and the grams of sand as the abscissæ, they form a straight line from the initial resistance of the solution to the point where it is fully absorbed in the sand and then another straight line with a different inclination throughout the range of the experiment. This is shown in the accompanying illustration (fig. 6).

INFLUENCE OF THE TEXTURE OF SOILS UPON THE ELECTRICAL RESISTANCE.

It appears evident from the results just given that the curvature of the solid grains of soil has the effect of lengthening the path between the electrodes and so of increasing the resistance between the electrodes. This would account for the increased resistance of 50 per cent when the sand was completely saturated with solution. Also the thickness of the films around the grains would play an important part in influencing the electrical resistance of soils short of saturation.

To test the first proposition one of the hard rubber cells was filled half full with a salt solution and the resistance taken. A glass marble was then introduced which would just fit into the cell. This sphere in touching the bottom and sides of the cube left about 50 per cent by volume of space in the cell. The liquid therefore rose so as to completely fill the cell and just cover the marble. This increased the resistance on the average from 35 to 45 per cent as the result of a number of trials. When several smaller marbles were put into the cell and symmetrically arranged they had the same influence on the resistance as a single large marble, and it is evident that a thousand balls sym-

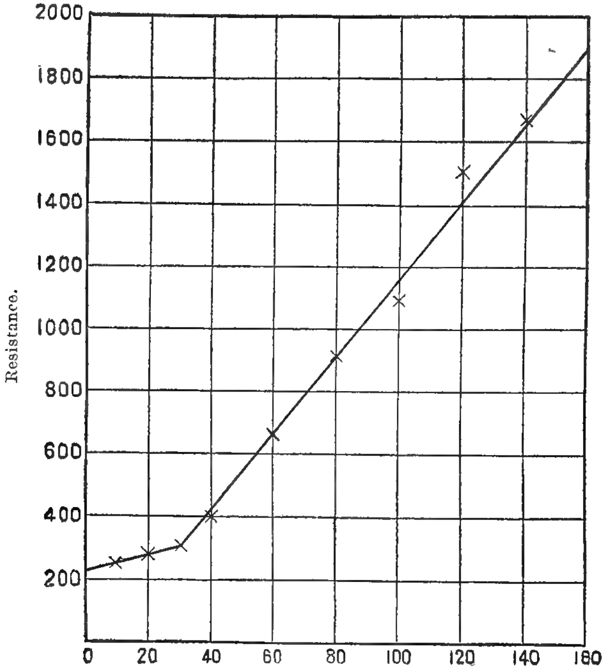

FIG. 6.—Influence of quartz sand on the electrical resistance of a salt solution.

metrically arranged which just filled the cell would have the same effect on the resistance of the solution as a single one of the larger size. This, therefore, accounts for the increase of 50 per cent in the resistance of the solution when sufficient quartz sand was introduced to just absorb it.

To investigate the matter further a soap solution was made up after the well-known formula of Plateau, composed of pure water, castile soap, and glycerin. A quantity of this was put into a hard rubber cell and the resistance taken. Some of the solution was then beaten up into a fine foam with an egg-beater and a quantity of the foam equal in weight to the solution was put into the cell, when it was found that the resistance of the foam was about 30 or 40 per cent greater than the resistance of the solution.

It has been noticed that a fine-grained clay soil has a very much higher resistance with the same percentage of water than a coarse-grained sandy soil. In order to see if the texture of the soil really has an influence upon the resistance, the specific resistance and the salt content of several soils and mixtures of soils having very different textures were determined. An amount of soluble salt was then added to each soil to make a uniform amount of salt in the soils. The specific resistance was then determined. The soils had the same salt content and the same water content, the only difference being in the texture. This investigation was made with approximately 12 per cent of water in all the soils and also with all the soils saturated with water. The results are given in the accompanying tables:

Influence of the texture of soils containing approximately 12 per cent of water and a uniform salt content upon the electrical resistance.

Soil.	Per cent moisture.	Salt in 1 gram soil.	Specific resistance (1 cc. soil=1.33 grams).	
			Natural soil.	Uniform salt in all soils. *a*
		mg.		
Early truck, Maryland	10.86	0.1021	20,110	4,080
Three parts early truck, Maryland; One part limestone, Virginia	11.64	.1695	20,830	7,190
Two parts early truck, Maryland; One part limestone, Virginia	11.81	.2051	29,360	9,000
Limestone, Pennsylvania	11.44	.3628	22,900	14,440
Limestone, Kentucky	11.67	.2255	26,030	14,820
Limestone, Virginia	12.10	.4204	72,180	40,670

Soil.	Surf. area 1 gram soil. *b*	Thickness of film of water. *c*	Increase tempt. of mixt. *d*	Ratio.		
				Increase in tempt.	Surf. area.	Sp. res.
	Sq. cm.	*mm.*	° *F.*			
Early truck, Maryland	600	0.0001811	0.11	4	15	28
Three parts early truck, Maryland; One part limestone, Virginia	2,212	.0000526	2.08	72	54	50
Two parts early truck, Maryland; One part limestone, Virginia	2,749	.0000430	2.12	74	67	62
Limestone, Pennsylvania	4,089	.0000280	2.87	100	100	100
Limestone, Kentucky	4,339	.0000269	3.68	128	106	103
Limestone, Virginia	7,048	.0000172	4.87	170	172	282

a For this determination sufficient salt was added to each soil to make a uniform content of 0.5 mg. of soluble salt per gram of soil.

b Calculated from the mechanical analyses by formula given in Weather Bureau Bulletin No. 4.

c Assuming that the actual amount of water present in the soil as shown in the first column was spread on a plane surface equal in extent to the total surface area of the soil grains in 1 gram of soil.

d Method of Gore, see next page.

Influence of the texture of soils containing a uniform salt content and saturated with water upon the electrical resistance.

Soil.	Wt. soil to 10 cc. water.	Salt in 1 gram soil.	Actual resistance.	Resistance calc. *a*	Res. soil: 10 cc. sol=1. *b*
		mg.			
Early truck, Maryland	48.7	0.1520	480	399	1.48
Three parts early truck, Maryland; One part limestone, Virginia	33.2	.2066	498	477	1.77
Two parts early truck, Maryland; One part limestone, Virginia	30.8	.2932	502	496	1.84
Limestone, Pennsylvania	24.1	.2838	498	554	2.06
Limestone, Kentucky	20.5	.2356	470	563	2.09
Limestone, Virginia	15.6	.6731	490	699	2.59

a On basis of 30 grams soil and uniform salt content.
b The solution contained in each case 3.968 mg. of salt per cubic centimeter. This was equal to the actual amount of salt in the soil and the amount added to make up to a uniform quantity in each case. The resistance of 10 cc. of NaCl solution of this strength in the cell used was 270 ohms.

With the same water and salt content the specific resistance of the fine-grained limestone soil, containing upward of 60 per cent of clay, when saturated with water was nearly twice as great as the resistance of the early truck soil containing less than 5 per cent of clay. When the soils contained approximately 12 per cent of water the resistance of the limestone soils containing the same amount of soluble salt and the same amount of water was ten times greater than the resistance of the early truck. To see if the influence in specific resistance with 12 per cent of moisture was proportional to the difference in texture the following calculations were made. The approximate surface area of the grains in 1 gram of soil was calculated from the mechanical analysis by a formula given in Weather Bureau Bulletin No. 4. It is seen that when the soils are arranged in the order of the specific resistances with a uniform salt content they are also arranged in the order of the surface area. The relative extent of surface area of the grains was next determined by a method described by Gore.[1] One hundred grams of soil, with the lumps thoroughly rubbed down, were carefully poured, with proper precautions, into 50 cc. of water at the same temperature into which the bulb of a sensitive thermometer dipped which could be read to 1-100 degree Centigrade. As the liquid spreads over the surface of the grains, a rise in temperature occurs which is proportional to the surface of the soil grains. The rise in temperature under these conditions is given in the table for the several soils. Taking the limestone soil from Pennsylvania as a unit, the ratio of the increase of temperature, the surface area, and the specific resistance show a general agreement which is certainly very striking.

In studying the influence of texture on the electrical resistance it is not necessary to actually adjust the salt content to a uniform value, as the resistance may be calculated for any other salt content if the resist-

[1] Change of temperature caused by contact of liquid with powdered silica, etc. G. Gore Phil. Mag., vol. 37, 1894, pp. 306–316.

ance for a certain content is known. This is done by the use of the following formula:

$$R_u = \frac{R\,S}{S_u},$$

where R_u = resistance of soil with unit quantity salt; R = resistance of natural soil; S = salt in natural soil; S_u = unit quantity salt, usually .5 mg. per gram.

It is evident that the size of the capillary spaces in a saturated soil and the thickness of the film of water around the soil grains when the soil is short of saturation have a marked influence upon the resistance of the soil.

If the amount of water present in the soils containing 12 per cent by weight was uniformly spread over an area equal to the estimated area of the soil grains, in each case the thickness of the film as given in the table would be comparable to the thickness of the thinnest portion of a soap bubble when it turns black just before bursting. The films of water around the grains of a moist soil are thus so exceedingly thin that they lose the properties of a liquid in mass. The small capillary spaces in the soil and the thin films in soils short of saturation offer a greater resistance to the electric current than is offered by a similar solution in bulk.

If a cell were filled with pure quartz sand and salt solution was introduced from below so as to saturate a layer of soil 1 centimeter deep and the solution was prevented from spreading, it would seem at first sight as though the resistance should be the same as though the same quantity of solution was uniformly mixed with the soil. Notwithstanding the increase in the area of the electrodes the resistance would increase on account of the higher resistance in the thin film of water around the soil grains.

As the amount of water in the soil is decreased by evaporation air spaces must form and must enlarge. Films will therefore have to break and all the films will not be continuous in the soil from one electrode to the other. If the films break *in the same way* and the solubility of the soil is not changed, any particular soil should always have the same resistance for any given percentage of water and salt content. It would seem possible that with a change in the surface tension of the soil moisture the mean thickness of the film around the grains and the way in which the films break would be somewhat affected and that this might have some influence on the resistance. This is an interesting line of investigation, which should be followed out.

REDUCTION OF ELECTRICAL RESISTANCES TO A UNIFORM TEMPERATURE.

In order to compare the electrical resistances of soils intelligently it is necessary to reduce them all to a uniform temperature. In this Division the resistances are all reduced to a temperature of 60° F.

Reduction of the electrical resistance of soils to a uniform temperature of 60° F.

°F.	1000	2000	3000	4000	5000	6000	7000	8000	9000
32.0	625	1,250	1,875	2,500	3,125	3,750	4,375	5,000	5,625
32.5	632	1,265	1,897	2,530	3,163	3,795	4,425	5,059	5,691
33.0	640	1,280	1,920	2,560	3,200	3,840	4,480	5,120	5,760
33.5	647	1,294	1,941	2,588	3,235	3,883	4,530	5,177	5,824
34.0	653	1,306	1,959	2,612	3,265	3,918	4,571	5,224	5,877
34.5	660	1,320	1,980	2,640	3,300	3,960	4,620	5,280	5,940
35.0	668	1,336	2,004	2,672	3,340	4,008	4,676	5,344	6,012
35.5	675	1,350	2,025	2,700	3,375	4,050	4,725	5,400	6,075
36.0	683	1,366	2,049	2,732	3,415	4,098	4,781	5,464	6,147
36.5	690	1,380	2,070	2,760	3,450	4,140	4,830	5,520	6,210
37.0	698	1,396	2,094	2,792	3,490	4,188	4,886	5,584	6,282
37.5	704	1,408	2,112	2,816	3,520	4,224	4,928	5,632	6,336
38.0	711	1,422	2,133	2,844	3,555	4,266	4,977	5,688	6,399
38.5	717	1,434	2,151	2,868	3,585	4,302	5,019	5,736	6,453
39.0	723	1,446	2,169	2,892	3,615	4,338	5,061	5,784	6,507
39.5	729	1,458	2,187	2,916	3,645	4,374	5,103	5,832	6,561
40.0	735	1,470	2,205	2,940	3,675	4,410	5,145	5,880	6,615
40.5	742	1,484	2,226	2,968	3,710	4,452	5,194	5,936	6,678
41.0	750	1,500	2,250	3,000	3,750	4,500	5,250	6,000	6,750
41.5	757	1,514	2,271	3,028	3,785	4,542	5,299	6,056	6,813
42.0	763	1,526	2,289	3,052	3,815	4,578	5,341	6,104	6,867
42.5	770	1,540	2,310	3,080	3,850	4,620	5,390	6,160	6,930
43.0	776	1,552	2,328	3,104	3,880	4,656	5,432	6,208	6,984
43.5	782	1,564	2,346	3,128	3,910	4,692	5,474	6,256	7,038
44.0	788	1,576	2,364	3,152	3,940	4,728	5,516	6,304	7,092
44.5	794	1,588	2,382	3,176	3,970	4,764	5,558	6,352	7,146
45.0	800	1,600	2,400	3,200	4,000	4,800	5,600	6,400	7,200
45.5	807	1,614	2,421	3,228	4,035	4,842	5,649	6,456	7,263
46.0	814	1,628	2,442	3,256	4,070	4,884	5,698	6,512	7,326
46.5	821	1,642	2,463	3,284	4,105	4,926	5,747	6,568	7,389
47.0	828	1,656	2,484	3,312	4,140	4,968	5,796	6,624	7,452
47.5	835	1,670	2,505	3,340	4,175	5,010	5,845	6,680	7,515
48.0	843	1,686	2,529	3,372	4,215	5,058	5,901	6,744	7,587
48.5	850	1,700	2,550	3,400	4,250	5,100	5,950	6,800	7,650
49.0	856	1,712	2,568	3,424	4,280	5,136	5,992	6,848	7,704
49.5	862	1,724	2,586	3,448	4,310	5,172	6,034	6,896	7,758
50.0	867	1,734	2,601	3,468	4,335	5,202	6,069	6,936	7,803
50.5	874	1,748	2,622	3,496	4,370	5,244	6,118	6,992	7,866
51.0	881	1,762	2,643	3,524	4,405	5,286	6,167	7,048	7,929
51.5	887	1,774	2,661	3,548	4,435	5,322	6,209	7,096	7,983
52.0	893	1,786	2,679	3,572	4,465	5,358	6,251	7,144	8,037
52.5	900	1,800	2,700	3,600	4,500	5,400	6,300	7,200	8,100
53.0	906	1,812	2,718	3,624	4,530	5,436	6,342	7,248	8,154
53.5	912	1,824	2,736	3,648	4,560	5,472	6,384	7,296	8,208
54.0	917	1,834	2,751	3,668	4,585	5,502	6,419	7,336	8,253
54.5	925	1,850	2,775	3,700	4,625	5,550	6,475	7,400	8,325
55.0	933	1,866	2,799	3,732	4,665	5,598	6,531	7,464	8,397
55.5	940	1,880	2,820	3,760	4,700	5,640	6,580	7,520	8,460
56.0	947	1,894	2,841	3,780	4,735	5,682	6,629	7,576	8,523
56.5	954	1,908	2,862	3,816	4,770	5,724	6,678	7,632	8,586
57.0	961	1,922	2,883	3,844	4,805	5,766	6,727	7,688	8,649
57.5	968	1,936	2,904	3,872	4,839	5,807	6,775	7,743	8,711
58.0	974	1,948	2,922	3,896	4,870	5,844	6,818	7,792	8,766
58.5	981	1,961	2,942	3,923	4,903	5,884	6,864	7,845	8,826
59.0	987	1,974	2,962	3,949	4,936	5,923	6,910	7,898	8,885
59.5	994	1,988	2,982	3,976	4,971	5,965	6,959	7,953	8,947
60.0	1,000	2,000	3,000	4,000	5,000	6,000	7,000	8,000	9,000
60.5	1,006	2,013	3,019	4,026	5,032	6,039	7,045	8,052	9,059
61.0	1,013	2,026	3,039	4,052	5,065	6,078	7,091	8,104	9,117
61.5	1,020	2,040	3,060	4,080	5,100	6,120	7,140	8,160	9,180
62.0	1,027	2,054	3,081	4,108	5,135	6,162	7,189	8,216	9,243
62.5	1,033	2,067	3,100	4,134	5,167	6,201	7,234	8,268	9,302
63.0	1,040	2,080	3,120	4,160	5,200	6,240	7,280	8,320	9,360
63.5	1,047	2,094	3,141	4,188	5,235	6,282	7,329	8,376	9,423
64.0	1,054	2,108	3,162	4,216	5,270	6,324	7,378	8,432	9,486
64.5	1,060	2,121	3,181	4,242	5,302	6,363	7,423	8,484	9,545
65.0	1,067	2,134	3,201	4,268	5,335	6,402	7,469	8,536	9,603
65.5	1,074	2,148	3,222	4,296	5,370	6,444	7,518	8,592	9,666

Reduction of the electrical resistance of soils to a uniform temperature of 60° F.—Cont'd.

°F.	1000	2000	3000	4000	5000	6000	7000	8000	9000
66.0	1,081	2,162	3,243	4,324	5,405	6,486	7,567	8,648	9,729
66.5	1,088	2,176	3,264	4,352	5,440	6,528	7,616	8,704	9,792
67.0	1,095	2,190	3,285	4,380	5,475	6,570	7,665	8,760	9,855
67.5	1,102	2,205	3,307	4,410	5,512	6,615	7,717	8,820	9,922
68.0	1,110	2,220	3,330	4,440	5,550	6,660	7,770	8,880	9,990
68.5	1,117	2,235	3,352	4,470	5,587	6,705	7,823	8,940	10,058
69.0	1,125	2,250	3,375	4,500	5,625	6,750	7,875	9,000	10,125
69.5	1,133	2,265	3,398	4,530	5,663	6,795	7,928	9,060	10,193
70.0	1,140	2,280	3,420	4,560	5,700	6,840	7,980	9,120	10,260
70.5	1,147	2,295	3,442	4,590	5,737	6,885	8,032	9,180	10,327
71.0	1,155	2,310	3,465	4,620	5,775	6,930	8,085	9,240	10,395
71.5	1,162	2,325	3,487	4,650	5,812	6,975	8,137	9,300	10,462
72.0	1,170	2,340	3,510	4,680	5,850	7,020	8,190	9,360	10,530
72.5	1,177	2,355	3,532	4,710	5,887	7,065	8,242	9,420	10,597
73.0	1,185	2,370	3,555	4,740	5,925	7,110	8,295	9,480	10,665
73.5	1,193	2,386	3,579	4,772	5,965	7,158	8,351	9,544	10,737
74.0	1,201	2,402	3,603	4,804	6,005	7,206	8,407	9,608	10,809
74.5	1,208	2,416	3,624	4,832	6,040	7,248	8,456	9,664	10,872
75.0	1.215	2,430	3,645	4,860	6,075	7,290	8,505	9,720	10,935
75.5	1,222	2,445	3,667	4,890	6,112	7,335	8,557	9,780	11,002
76.0	1,230	2,460	3,690	4,920	6,150	7,380	8,610	9,840	11,070
76.5	1,237	2,475	3,712	4,950	6,187	7,425	8,662	9,900	11,137
77.0	1,245	2,490	3,735	4,980	6,225	7,470	8,715	9,960	11.205
77.5	1,253	2,506	3,759	5,012	6,265	7,518	8,771	10,024	11,277
78.0	1,261	2,522	3,783	5,044	6,305	7,566	8,827	10,088	11,349
78.5	1,269	2,538	3,807	5,076	6,345	7,614	8,883	10,152	11,421
79.0	1,277	2,554	3,831	5,108	6,385	7,662	8,939	10,216	11,493
79.5	1,285	2,576	3,856	5,142	6,427	7,713	8,998	10,284	11,569
80.0	1,294	2,598	3,882	5,176	6,470	7,764	9,058	10,352	11,646
80.5	1,302	2,609	3,906	5,208	6,510	7,812	9,114	10,416	11,718
81.0	1,310	2,620	3,930	5,240	6,550	7,860	9,170	10,480	11,790
81.5	1,318	2,637	3,955	5,274	6,592	7,911	9,229	10,546	11,866
82.0	1,327	2,654	3,981	5,308	6,635	7,962	9,289	10,616	11,943
82.5	1,335	2,670	4,005	5,340	6,675	8,010	9,345	10,680	12,015
83.0	1,343	2,686	4,029	5,372	6,715	8,058	9,401	10,744	12,087
83.5	1,351	2,702	4,053	5,404	6,755	8,106	9,457	10,808	12,159
84.0	1,359	2,718	4,077	5,436	6,795	8,154	9,513	10,872	12,231
84.5	1,367	2,735	4,102	5,470	6,837	8,205	9,572	10,940	12,307
85.0	1,376	2,752	4,128	5,504	6,880	8,256	9,632	11,008	12,384
85.5	1,385	2,769	4,153	5,538	6,922	8,307	9,691	11,076	12,460
86.0	1,393	2,786	4,179	5,572	6,965	8,358	9,751	11,144	12,537
86.5	1,401	2,802	4,203	5,604	7,005	8,406	9,807	11,208	12,609
87.0	1,409	2,818	4,227	5,636	7,045	8,454	9,863	11,272	12,681
87.5	1,418	2,836	4,254	5,672	7,090	8,508	9,931	11,344	12,762
88.0	1,427	2,854	4,281	5,708	7,135	8,562	9,989	11,416	12,843
88.5	1,435	2,870	4,305	5,740	7,175	8,610	10,040	11,480	12,915
89.0	1,443	2,886	4,329	5,772	7,215	8,658	10,091	11,544	12,987
89.5	1,451	2,903	4,354	5,806	7,257	8,709	10,155	11,612	13,063
90.0	1,460	2,920	4,380	5,840	7,300	8,760	10,220	11,680	13,140
90.5	1,468	2,937	4,405	5,874	7,342	8,811	10,279	11,748	13,216
91.0	1,477	2,954	4,431	5,908	7,385	8,862	10,339	11,816	13,293
91.5	1,486	2,972	4,458	5,944	7,430	8,916	10,402	11,888	13,374
92.0	1,495	2,990	4,485	5,980	7,475	8,970	10,465	11,960	13,455
92.5	1,504	3,008	4,512	6,016	7,520	9,024	10,528	12,032	13,536
93.0	1,513	3,026	4,539	6,052	7,565	9,078	10,591	12,104	13,617
93.5	1,522	3,035	4,567	6,090	7,612	9,135	10,657	12,180	13,702
94.0	1,532	3,064	4,596	6,128	7,660	9,192	10,724	12,256	13,788
94.5	1,541	3,083	4,624	6,166	7,707	9,249	10,790	12,332	13,873
95.0	1,551	3,102	4,653	6,204	7,755	9,306	10,857	12,408	13,959
95.5	1,560	3,121	4,681	6,242	7,802	9,363	10,923	12,484	14,040
96.0	1,570	3,140	4,710	6,280	7,850	9,420	10,990	12,560	14,130
96.5	1,580	3,160	4,740	6,320	7,900	9,480	11,060	12,640	14,220
97.0	1,590	3,180	4,770	6,360	7,950	9,540	11,130	12,720	14,310
97.5	1,600	3,201	4,801	6,402	8,002	9,603	11,203	12,804	14,404
98.0	1,611	3,222	4,833	6,444	8,055	9,666	11,277	12,888	14,499
98.5	1,620	3,240	4,860	6,480	8,100	9,720	11,340	12,960	14,580
99.0	1,629	3,258	4,887	6,516	8,145	9,774	11,403	13,032	14,661

This reduction can readily be made by the use of the preceding table, which has been calculated from the temperature coefficient of nine types of soil described in Bulletin No. 7.

A single illustration will serve to show the way this table is used. Suppose the observed resistance of the soil is 2,585 ohms at a temperature of 50.5°. In the table at the temperature of 50.5°, as indicated on the left-hand side, we find that at that temperature 2,000 ohms is equal to 1,748 ohms at 60°; 5,000 ohms is equal to 4,370 ohms at 60°, hence 500 ohms would be equal to 437 ohms. Similarly 80 ohms would be one-hundredth of the value given for 8,000 ohms at 50.5° in the table, therefore, equal to about 70 ohms at 60°; while the 5 ohms would be equal to about 4 ohms. These separate values are added together thus:

2,000	1,748
500	437
80	70
5	4

2,585 ohms at 50.5° = 2,259 ohms at 60°

The table is constructed only for intervals of 0.5° F. Ordinarily this is close enough. A temperature between a whole degree and a half degree, more or less, is either increased or diminished, so as to make it a whole degree or a half degree. If it is desired to work closer than this it can be done by interpolation in the table.

BULLETIN No. 9.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF SOILS.

SOIL MOISTURE:

A RECORD OF

THE AMOUNT OF WATER CONTAINED IN SOILS

DURING

THE CROP SEASON OF 1896.

BY

MILTON WHITNEY AND RALPH S. HOSMER.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS,
Washington, D. C., April 24, 1897.

SIR: I have the honor to transmit herewith data showing the amount of moisture in the soils of a number of localities in the United States during the crop season of 1896, together with brief notes as to the character of the season in the different localities. I recommend that this be published as Bulletin No. 9 of this Division.

Respectfully,

MILTON WHITNEY,
Chief of Division.

HON. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

SOIL MOISTURE: A RECORD OF THE AMOUNT OF WATER CONTAINED IN SOILS DURING THE CROP SEASON OF 1896.

INTRODUCTION.

Records were kept of the moisture conditions during the season of 1895 in a number of different types of soils and published during the year in three bulletins. These investigations were continued during the season of 1896, the results of which are presented in this publication. In a number of cases the records were continued in the same places as in the previous year, but in order to extend the preliminary investigations over a wide range of soil conditions, some of the observations were discontinued and other areas were taken up.

The relative water-holding power of soils under similar climatic conditions and exposure depends largely upon the texture—that is, the relative amount of sand, silt, clay, and organic matter—and upon the structure or arrangement of the grains. It likewise depends to a considerable extent, of course, upon local conditions of depth, compactness, exposure, cropping and cultivation, and the surface tension of the soil moisture. A system of classification of soils based upon the physical properties of texture, structure, and water-holding power was suggested in Weather Bureau Bulletin No. 4. This has been confirmed by extensive field examinations and physical analyses of over 1,200 samples carefully collected from different types of soils adapted to various classes of crops from all parts of the United States and from several foreign countries. The texture of a number of these important types of soils was illustrated graphically in Bulletin No. 5 of this Division.

It has been pointed out before that differences in the physical properties of soils, and particularly in the texture, will cause varying proportions of the rainfall to be retained. Clay soils, as a rule, offer great resistance to rain, and the movement of the water downward through them is so slow that a large quantity remains at the disposal of crops during the ordinary season. Sandy soils, on the contrary, are usually so open and porous that they offer little resistance to the descent of rain and retain but a small amount of water. As plants differ greatly in the amount of water required for their best development, this is one of the principal reasons for the peculiar adaptation of certain soils to certain plants and a controlling condition in the distribution of plants. It is apparent nearly every year that the moisture content of soils is a limiting factor in crop production, and with extensive farming, at least, the crop fluctuates greatly with the character of the season. With intensive cultivation the character of the season is of much less moment, for most of the soil conditions may be largely controlled or modified when the value of the crop justifies the necessary time, labor, and expense.

It is necessary, therefore, for the highest development of the agricultural possibilities of any soil, or the material modification of the yield or quality of any crop, to study the moisture conditions of our various types of soils and the extent to which these conditions can be modified or changed by methods of cropping, fertilization, or cultivation.

In a number of cases the records have been continued long enough and the weather conditions have been diverse enough to make it possible approximately to establish lines of excessive moisture and of drought in the soils. The curves illustrate in a graphic way the conditions in several soils during a period of quite marked drought, during which crops suffered, in the season of 1896. The condition of the ground as to moisture is a most important factor in crop production, for so long as the moisture is below the minimum required for the normal functions of the plant this will be a limiting condition in the development of the crop. The object of ordinary cultivation, and possibly one of the important objects of fertilization, as well as the whole object of irrigation, is to conserve or increase the moisture and prevent the excessively dry conditions known as droughts. With frequent, well-distributed showers cultivation would hardly be necessary except occasionally to change the mechanical condition of the soil in the neighborhood of the plants and to destroy the larger weeds; but with very infrequent and variable rainfalls cultivation is required as a protection against excessive loss of moisture. The records here published show the frequency, extent, and duration of the dry periods in the several localities and indicate the conditions which must be controlled by improved methods of cultivation and manuring, or by the application of water through irrigation, if this limiting cause is to be controlled.

It will be observed that the results presented in this bulletin are for a depth of 12 inches. In the case of shallow-rooted crops, of course, the surface may be quickly dried out and a drought of short duration occur which would not be indicated by the data for the depth of 12 inches. Furthermore, soil conditions which would be favorable under certain conditions of temperature, sunshine, and wind would not necessarily be favorable under different conditions. Most of our cultivated plants will do well on a soil containing a large percentage of moisture, providing the temperature is high and there is an abundant amount of sunshine, while there would be much more danger of injury to the crops if these very moist conditions prevailed during a cold, cloudy period.

METHOD OF MAKING MOISTURE DETERMINATIONS.

The method of making the moisture determinations in these investigations was the same as that used last year and described in Bulletin No. 4 of this Division. It consists of taking samples of the soil in a small brass tube driven into the ground to the desired depth and drying the sample so obtained at a temperature of 110° C., the loss in weight representing the amount of moisture. It has been shown in Bulletin No. 6 that this method is not very convenient and has a wide range of probable error. A single determination is not to be relied upon within 2 per cent, more or less, of the value which would be obtained if a great many samples were taken and the results averaged. The error is believed to be mainly due to the inequalities of the soil and to the difficulty of taking samples which represent the actual depth intended. Owing to these causes the daily moisture determinations fluctuate considerably without any apparent cause. For this reason it is necessary to plot the daily records on cross-section paper and draw a curve or line occupying a mean position between the daily points. This eliminates most of the apparently unwarrantable daily variations. Care must be taken in doing this not to attempt to make a smooth curve nor to eliminate all inequalities, but merely to give the line a certain mean position which will represent more truly the moisture conditions for any given date than would the actual moisture determination for that day. This method of plotting has been described and illustrated in Bulletin No. 4.

The records given in the pre ent bulletin are, therefore, not the actual field records, but are obtained by plotting these records and taking for each day the per cent of moisture shown for that day by the curve.

CALCULATION OF RESULTS.

It was shown in Bulletin No. 4 that there are three ways in which the amount or percentage of water in the soil may be expressed, namely: (*a*) The weight per unit volume of soil, (*b*) the per cent of dry weight of soil, and (*c*) the p r cent of fresh weight of s il. The first method would be decidedly the best if one could readily determine the weight of a unit volume of soil. If the amount of moisture should be expressed in cubic inches or cubic feet of soil, the figures would be not only always comparable for the same soil but for others; that is, if a soil contained 20 cubic inches of water per cubic foot there would be twice as much water present as when the same soil, or when any other soil, contained 10 cubic inches per cubic foot.

This simple relation does not hold with either of the other methods of expressing the water content. If the amount is expressed in percentage of the fresh weight, as in an ordinary chemical analysis, a given volume of soil containing 20 per cent of water does not contain twice as much water as when the same volume contains 10 per cent, owing to the difference in the composition and consequent difference in the fresh weight of the material upon which the percentage is based. Furthermore, if a soil contains 20 per cent of its fresh weight of moisture, it does not necessarily contain the same amount of water per cubic foot or, roughly speaking, per acre as another soil having a different texture and containing the same percentage of water, owing to the difference in the weight of a cubic foot of sand and a cubic foot of clay.

Lastly, if the amount of water is calculated on the basis of dry weight of soil, this is always a constant factor, and a soil containing 20 per cent of water will have twice as much water present as when there is 10 per cent of water. Here again, however, owing to the difference in the weight of a unit volume of soils, 20 per cent of water in one soil does not necessarily represent the same quantity of water per cubic foot or per acre as 20 per cent would in another soil.

In order that the results may be strictly and easily comparable for the same soil and that the percentage may show directly the relative amount of water in the soil it has seemed best to change the practice followed in 1895 and to figure the percentage of moisture this year on the dry weight of soil. The figures for 1896 are therefore not strictly comparable with those for 1895, but they may be readily converted from one to the other. The following table shows the ratios of the percentages of water, both as calculated on the fresh weight and as calculated on the dry weight, and by interpolation the figures from one system can readily be converted into the other:

Per cent.		Per cent.	
Fresh weight.	Dry weight.	Fresh weight.	Dry weight.
1	1.01	14	16.28
2	2.04	15	17.25
3	3.09	16	19.04
4	4.17	17	20.47
5	5.26	18	21.96
6	6.38	19	23.46
7	7.52	20	24.99
8	8.74	21	26.59
9	9.88	22	28.20
10	11.11	23	29.86
11	12.36	24	31.58
12	13.63	25	33.33
13	14.94		

CONDITIONS INFLUENCING THE RELATIONS OF SOILS TO WATER.

The record of moisture conditions in a number of types of soil is given in the tables, while the kind of soil and the character of the season are briefly described in the following paragraphs.

As the final product of a crop is frequently determined not so much by the average conditions as by the limiting conditions of excessive wetness or drought in the soils, considerable attention has been given to determining the conditions prevailing under these extremes and the range of the moisture conditions in each of the soils which is most favorable to the proper growth and development of the crops adapted to the soils. In view of the importance of these limiting conditions of drought and excessive wetness, the conditions prevailing in the soils during such periods, wherever they have occurred, are shown graphically in the diagrams at the end of this bulletin. A careful study of these will show the existing conditions of growth and will indicate the direction and the extent to which these conditions must be changed by cultivation, fertilization, or cropping in order to secure the highest development of the land in its agricultural aspect.

A careful study of the tables and of the diagrams will show some inequalities and variations which can not at first sight be explained by the conditions of rainfall or evaporation. It will be well, therefore, to mention briefly the conditions which may influence the relation of rainfall and soil moisture.

In addition to the texture and structure of soils, the amount of organic matter and depth, there are some other conditions which will influence the moisture content of soils. In the first place, a light rain, especially when it falls on a dry soil, may evaporate so quickly as not appreciably to influence the water content of the soil a few minutes afterwards. On the other hand, the rain may be so heavy and sudden that most of it will run off over the surface and have little or no influence upon the water content of the soil at the time the daily sample is taken.

A light shower falling on the dry soil and diluting the soil moisture with nearly pure water will increase the surface tension, or "pulling" power, of the water, so that more water will be brought up from below. If a rapid and excessive evaporation takes place, the water which falls and part of that which has been drawn up from below may evaporate and the soil be left drier than if the rain had not fallen. If, on the other hand, evaporation be retarded after the rainfall, the water content of the surface foot of soil near the surface may continue to increase by reason of the higher surface tension of the moisture near the top of the ground, and this increase may continue for several days, while the moisture conditions are gradually adjusting themselves. This is apparently indicated by some of the data in the tables where the water content appears to increase in a number of cases for several days after the rain has fallen.

The water content of the upper foot of soil may actually increase in the absence of rain, in the event of any material diminution in the rate of evaporation from the surface of the ground. If water evaporates from the surface of the soil at the rate of 1 pound per unit of area per day, water must be constantly moving up from the lower depths to supply the surface with at least part of that which evaporates. It can not under normal field conditions supply all. It requires time for water to move up through the soil and adjust itself to any change of condition. If, therefore, from any cause evaporation from the surface is retarded, it is likely that for a while the upward movement will continue and after a time more water will be contained in the surface foot of soil than if evaporation had continued at the normal rate. This appears to be shown in some of the records. This may also account for the apparent increase in the moisture content in the soils a day or two before rains are recorded, as indicated in many cases, for the atmosphere is liable to contain much moisture at such times and the evaporation be considerably reduced.

SOIL CONDITIONS DURING THE SEASON OF 1896.

EARLY TRUCK LAND, MARDELA SPRINGS, MD.

Records were continued in the early truck soils at Mardela Springs, with the same results as in the previous year. Records of soil moisture, together with the rainfall, are given (pp. 13–23). The moisture conditions during April were considered very favorable for the growing crops, with the exception that very high temperatures prevailed from April 13 to 20 and evaporation was so excessive that the soil was hardly moist enough for the plants, and there was some wilting. From May 2 to 9 the conditions were considered favorable; from 10 to 19 the soil was rather too dry. The remainder of the month was favorable. The first few days of June were favorable; the middle of the month was rather dry, and after the 21st the soil conditions were reported as being very dry. The first five days of July the soil continued dry. The frequent rains from the 6th to the 10th kept the surface rather wet, while the remainder of the month, with the exception of the last two days, was considered favorable. From July 30 to August 14 the soil was extremely dry and the period was referred to as a severe drought, corn dying and other crops suffering excessively. The soil conditions during the rest of the month of August were generally favorable. During the month of September the soil was considered rather wet for the time of year.

Curves are given illustrating the soil conditions during a good growing period in March and April and during a severe drought of July and August. The records for this year seem to confirm those for last season, and indicate that the most favorable moisture conditions for this soil range from 5 to 8 per cent. When the moisture falls much below 5 per cent crops suffer from drought, while if the moisture content increases to 10 per cent or over the crops suffer from excess of water. So during the latter part of July and the first half of August the moisture curve was below the line of drought for about sixteen days. At certain periods of growth such conditions might prove fatal to any of our crops. They must be prevented or much alleviated by cultivation or by irrigation in order to save the crops from serious harm. Such conditions are but too often the controlling conditions of crop production.

KENTUCKY BLUEGRASS LAND, LEXINGTON, KY.

Records were continued in the bluegrass land at Lexington, Ky., both in the sod and in an adjacent plot from which the sod was removed, but which was not disturbed during the season, except that all vegetation was kept off with a hoe. The soil during the first half of June was considered rather wet. During the latter part of June the surface was rather dry. In July there was one very wet period, from the 20th to the 27th. The remainder of the month was considered generally quite favorable. The first part of August the soil was considered rather wet. The remainder of the month, up to the last four days, was considered very favorable. During the month of September there was a severe drought, lasting almost the entire month.

Curves are given illustrating the moisture conditions during a wet period in early June and during the rather severe drought in September.

The results this year confirm the records of last season, and seem to show that for these soils 25 per cent is the limit, beyond which the soils become too wet, and 15 per cent the line below which the soil contains too little moisture.

COTTON LAND OF THE RED HILL FORMATION, ST. MATTHEWS, S. C.

Records were kept during the season in the Red Hill formation at St. Matthews, S. C., in order, if possible, to determine the conditions of favorable moisture content and the extremes of wet and dry conditions for the growth of cotton. With the exception of a wet period during the middle of July, the conditions throughout the season were considered generally favorable and normal for the growth of cotton. Curves are given illustrating the favorable conditions during the month of June, the most active growing period of the cotton crop, and also the good points of a season in September favorable for the ripening of cotton. It will be noticed that the conditions best for the growing period are very different from the best conditions for the ripening of cotton. The season was reported as being so uniformly good that it was not possible to establish the lines of excessive wet or of drought for this soil.

SANDY CRETACEOUS COTTON LAND, UNION SPRINGS, ALA.

Records are given of the moisture conditions in the sandy cretaceous lands of Union Springs, Ala., adapted to cotton. Curves are also given illustrating the wet and the favorable conditions for the growth of cotton in this soil during the month of June and the conditions during a prolonged drought during the month of September, when the soil was too dry even for the proper maturing of the cotton crop. The character of the season was such that it was possible to establish the line of excessive moisture at about 8 per cent and the line of drought at about 3 per cent for this soil. The tables and diagrams show for how much of the season the conditions were within these limits. There were two excessively wet seasons in June, the rest of the month being favorable. The middle of July also was considered too wet, while the very last of the month the soil was too dry for cotton. The weather generally throughout the month of August and the entire month of September was considered too dry for cotton.

SANDY CRETACEOUS COTTON LAND, FORT DEPOSIT, ALA.

Moisture conditions in the sandy cretaceous soil at Fort Deposit, Ala., were considered generally favorable throughout the season, except during the greater part of September, when the soil was reported too dry for cotton.

BLACK CRETACEOUS PRAIRIE COTTON LAND, MACON, MISS.

The curves for the season show that the line of drought in the black cretaceous prairie soils at Macon, Miss., is about 23 per cent, and that the favorable conditions for cotton require at least 25 or 27 per cent of moisture in the soil. A curve is given illustrating the dry period during the month of July, succeeded by a favorable season of about ten days' duration. During the months of August and September the soil was reported as continuously too dry.

It is interesting to compare the apparent line of drought in this soil with that in the sandy cretaceous land at Union Springs, Ala.

RICH BLACK CLAY LANDS OF THE MISSISSIPPI BOTTOM.

The observer at Greenville, Miss., states that the conditions in the Mississippi bottom soil at that place were uniformly too dry throughout the season. It may be seen that the rainfall records are very small. A curve is given illustrating the conditions in this soil during the month of June, when the moisture did not fall below 20 per cent. Nevertheless, the soil was too dry for cotton. The conditions during the season were not such that the lines of drought and of excessive moisture content could be established for this land.

BLACK WAXY SOIL, PARIS, TEX.

Records were kept of the moisture conditions in the black waxy soil at Paris, Tex., to study the actual moisture conditions in this very refractory soil. The ground was reported as too dry throughout the season, and the rainfall record shows that very little rain fell. Notwithstanding the total of rain was less than one-third of an inch during June, the diagram indicates that the moisture content hardly fell below 19 per cent, and the records show that it did not go below 12 per cent during the entire season. The season was so uniformly dry that the lines of drought and of excessive moisture could not be determined.

PRAIRIE, COLBY, KANS.

The records were continued at Colby, Kans., under the prairie sod and in plots cultivated in the ordinary way, subsoiled, and irrigated. The conditions were reported as uniformly favorable throughout the season, with an abundant, well-distributed rainfall. As during the favorable seasons of the previous year, the different methods of cultivation made little difference in the water content, while there was a very great difference in the water content of the prairie sod. The reason for this is probably that the rain does not readily enter the soil through the sod, and when it does enter, the grass uses a large supply and keeps the water content low. The other plots had no vegetation of any kind growing on them.

MOISTURE CONTENT OF SOILS.

MARDELA SPRINGS, MD.—1896

Early truck land.

Day.	April. Uncultivated.	April. Rain.	May. Uncultivated.	May. Rain.	June. Uncultivated.	June. Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1	10.5	0.65	5	0.08	6.8	....
2	9.5	....	7.5	....	6.5	....
3	8.8	....	8.2	....	6	....
4	8.9	....	8.4	.65	5.5	....
5	9.5	....	8	....	5.2	....
6	10	.03	7.5	.12	5.2	....
7	9.4	....	7	....	5	....
8	8.5	....	6.6	....	5	....
9	7	....	6	....	5	0.17
10	7.2	.08	5.4	....	5.1	.50
11	7.4	....	5	....	5.2	....
12	6.8	....	5	....	5.1	....
13	6.4	....	4.9	.15	5.2	Trace.
14	6.2	....	4.8	....	5.5	.49
15	6	....	4.6	....	6	....
16	5.5	....	4.5	....	5.6	....
17	5.2	....	4.8	....	5.5	.05
18	5	....	4.9	.07	5.6	.59
19	5.1	....	5.5	.16	5.4	....
20	5.2	.28	5.8	.38	5.1	....
21	5.1	....	6.4	....	4.9	....
22	4.9	....	6.6	.06	4.5	....
23	4.9	....	6.4	.07	5.1	....
24	6.2	....	6.4	....	3.8	....
25	6.2	.45	6	.01	3.5	....
26	5.5	....	5.6	.07	3.2	....
27	5.2	....	5.5	....	3	....
28	5	....	5.6	....	3.1	.17
29	5	....	6.1	.55	3.4	....
30	5	....	6.8	....	3.8	....
31	....	....	7	.57	....	....

Day.	July. Uncultivated.	July. Rain.	August. Uncultivated.	August. Rain.	September. Uncultivated.	September. Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1	4	....	4.2	....	5.2	....
2	4	....	4	....	5.4	....
3	3.9	....	3.8	....	5.8	....
4	3.9	....	3.5	....	6.8	0.64
5	4	....	3	....	8	.29
6	6.8	2.29	2.5	....	8.5	2.88
7	8.8	.52	2	....	8	....
8	8.8	Trace.	2	....	7	....
9	8.2	.14	2	....	6.5	....
10	7.8	.55	2	....	6.2	....
11	7	....	2	....	6.1	....
12	6.5	....	2	....	6.5	....
13	5.6	....	2.2	....	7.5	.77
14	5	....	2.5	....	8	....
15	4.6	....	5.5	1.58	8	....
16	5	.03	7	....	8	.50
17	5.2	.51	7.2	1.42	7.8	....
18	5.2	....	6.8	....	7.6	....
19	5.1	....	6.1	....	7.5	....
20	5	....	5.6	....	7.4	.74
21	5.4	.08	5.5	....	7.2	....
22	5.5	.11	6.2	.58	7.2	.08
23	5.7	....	7.2	.58	7.1	....
24	6.1	.60	7.2	.73	7	....
25	6.2	....	7.1	....	6.8	....
26	5.6	....	6.8	....	6.4	....
27	5	....	6.2	....	6	....
28	5.4	.16	5.8	....	5.8	....
29	5.4	....	5.5	....	6	....
30	4.5	....	5.2	....	7	....
31	4.2	....	5	....	....	....

LEXINGTON, KY.—1896.

Trenton limestone—Bluegrass land.

Day.	June.			July.			August.			September.		
	Bare.	Sod.	Rain.	Bare.	Sod.	Rain.	Bare.	Sod.	Rain.	Bare.	Sod.	Rain.
	P. ct.	*P. ct.*	*Inch.*	*P. ct.*	*P. ct.*	*Inch.*	*P. ct.*	*P. ct.*	*Inch.*	*P. ct.*	*P. ct.*	*Inch.*
1	26	19	1	23.5	16.6		25.3	27.2	0.42	22.6	15.8	
2	26.7	22		23.1	16		25	28.2	1.47	22.2	15	
3	27.2	27	1.35	23.2	15.8		24.1	28.3		22.1	14.4	0.33
4	27.6	27.8		23.8	15.4	.49	24	28.2		22.1	14.1	
5	27.7	27.7		23.9	14.9		24	28.2		22	14.3	.09
6	27.8	27.6	.75	23.8	14.4		24.3	28.1		21.6	14.3	
7	27.7	27.3		23.7	14.4		25.3	28	.57	21	14	
8	27.5	27.1	.40	24	17		26.1	27.8		20.8	13.6	
9	27.2	26.9	.60	27.9	25	1.59	25.8	27.3		20.4	13.5	
10	26.8	26.6		27.8	26		24.5	26		20.1	13.4	
11	26.7	26.3		27.5	25.5	.18	23	24.6		19.8	13.1	
12	26.7	26		27	24.7	.07	22.6	23.6		19.9	12.5	
13	26.7	25.7	.03	26.5	23		22.5	23		20.1	12	.01
14	26.8	25.4	.01	26	21.2		22.8	22.4		20.1	12.2	
15	26.9	24.9		26	21.2	.03	22.4	21.7		21.1	14.5	.23
16	26	23.5		26.1	23	.62	22.1	21.2	.07	21.3	15.1	
17	24.6	22.5	.03	26.1	23.5		21.8	20.5		21.2	15.2	
18	23.8	21		25.6	22.4		21.8	20.1		20.5	15	
19	23.3	19.5		25.5	22		22.2	20		20	14.4	.02
20	23.1	18		28.4	30.2	1.25	22.9	20.5		19.8	14	
21	23	16.7		29.8	30.3	2.30	23.5	21	.19	19.8	13.3	.01
22	23.4	16.4		29.7	30.2	1.03	24.2	21.2		19.9	12.7	
23	23.9	17.2	.63	29	30.2	1.02	24.6	21	.56	19.8	12	
24	24.4	16.5	.05	28.5	29.9	.01	24.9	21		19.5	11.2	
25	24.8	15.2		27.5	28.7		24.9	20.6		19.2	11.1	
26	25	15		26.5	27		24.9	20		19.1	11.3	
27	25.4	18.4	1.15	25	25.6		25.1	19.4	.04	20	13	.24
28	25.6	19.2	.05	22.5	23.7		25.7	18.6		25	21	1.49
29	25.2	18.6		22	22.3		25.8	17.9		27.9	25	1.76
30	24.5	17.6		23	22.3		25	17		27	27.5	.01
31				24.6	25.8	.56	23.8	16.3				

ST. MATTHEWS, S. C.—1896.

Red Hill formation—Cotton land.

Day.	June.		July.		August.		September.	
	Unculti-vated.	Rain.	Unculti-vated.	Rain.	Unculti-vated.	Rain.	Unculti-vated.	Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1	6	.80	6		4.4		4.5	
2	6.5		7.8	0.25	5.5		4	
3	10.8	1.01	9	.60	11	1.75	4	
4	11.8	.34	9		10.8		4.3	0.06
5	12	.04	11		10		3.8	
6	10.5		9.4	.72	9.6		3.4	
7	9.5		13	2.15	8.8		2.9	
8	9.2		12.9	1.33	8.5	.11	2.8	.06
9	9.5	.10	12.3	.25	7.8		2.8	
10	9.6	.36	11.8	.54	7.1		2.6	
11	9.4		11.5	.24	6.8		2.5	
12	8.9		11	.28	6.5	.28	2.4	
13	8.5	.40	10.5	.25	6.3	.03	2.4	
14	8.2		10	.24	6.8	.03	2.4	
15	7.9		9.5		8.1		2.5	
16	7.4		9	2.02	7.9		6	.15
17	7		17	2.34	7.5		6	
18	7		17.3	.22	7.5	.20	5.5	
19	9.5	.40	16	.47	7.5	.10	4.6	
20	12	1.64	13.8		7.2		4.3	
21	12	.25	11.8		5.6		4.3	
22	12	.02	10.3		4.5		5	.35
23	11.9		9.8		3.8		5	
24	11		9.5		3.8		4.9	
25	10		9.5		6.5		5	
26	8.8	.32	9.4		7.5	.10	4.8	1.37
27	7.9		8		7.8		3.9	
28	7		6.8		7.8		3.5	
29	6.8		6.3		7		10	
30	6.1		4.5		6.4	.60	10	
31			4		6.6			

UNION SPRINGS, ALA.—1896.

Sandy cretaceous cotton land.

Day.	June.		July.		August.		September.	
	Unculti-vated.	Rain.	Unculti-vated.	Rain.	Unculti-vated.	Rain.	Unculti-vated.	Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1	4.5		3.5	0.10	2	0.50	1.9	
2	11	1.45	7	1.34	1.6		1.5	
3	10.8	.70	7.1		1.5		1.2	
4	9	.20	6		1.4	Trace.	1.1	
5	8.2		5		1.3	.10	1.2	
6	8.3		6	2	1.3		1.8	
7	8.8		10		1.2		1.8	
8	8.9	.50	9.9	2.92	1.1	.10	1.5	
9	8.5		10		1.1		1	
10	7.8	.30	10	1.10	1		.9	
11	7.1		9	Trace.	1		1	
12	6.4		8.3	Trace.	1		.8	
13	5.6		8		.9		.6	
14	5.3		8.1	1	1	.06	.5	
15	4.7		7.9		1.5	.12	.6	
16	4.5		7.6		2.4	.65	.8	
17	4.2		7.6	.80	3.5		.9	
18	4.1		7.4	.10	5	2.15	.6	
19	11	4.69	6.4	Trace.	5.4		.6	
20	8.8		5.8		5		.6	
21	7.5		5.5		4.3		.6	
22	7.2	.09	5	.05	3.8		.6	0.05
23	6.6	Trace.	4.6		3.4		.8	
24	5.6	.20	4		3.3		1	
25	5.1		3.5		3.3	.20	1.1	
26	4.9		3		3.3		1	
27	4.5	Trace.	2.3		3.2		.8	
28	4.1	Trace.	2		3		.7	
29	3.8	.20	2.1		2.5		2.8	1.05
30	3.4		1.9		2		4	
31			2		1.9			

FORT DEPOSIT, ALA.—1896.

Sandy cretaceous land.

Day.	June.		July.		August.		September.	
	Unculti-vated.	Rain.	Unculti-vated.	Rain.	Unculti-vated.	Rain.	Unculti-vated.	Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent*	*Inch.*
1	11.8		5.5		7	0.20	1.5	
2	12.2	0.25	5		7.5		1.5	
3	13.5	1	5.5	0.12	6.5		2	0.05
4	14		5.5		5.4		2.2	
5	13		5.6		4.8		2.2	
6	12.3		5.8	.25	4.5		2	
7	12.2	.25	12.5	2	4.5		2	
8	12.3	.50	13.4		4.8		2	
9	12.2		13.2		4.7		1.9	
10	11.8	.20	13.1		4.3		1.8	
11	11.3		13		4.2		1.6	
12	11		13		4.5		1.5	
13	10.5		13		5.3	1	1.5	
14	10		13.3		5.2		1.4	
15	9.5		13.6		5.1		1.1	
16	9.1		14.5		4.8		1	
17	8.8		15		4.3		1.2	
18	8.6	Trace.	15.4	.68	3.8		1.3	
19	12.5	.75	15	.07	3		1.2	
20	12.5	.50	13.8		2.5		1.2	
21	11.4		12.5		2		1.3	
22	11.4		11.5		2.2		1.3	Trace.
23	12.4	.75	10.8		4.6	.25	1.4	
24	12		10	.50	5.1	.13	1.6	
25	10.8		9.5		4.5		1.6	
26	9.6		9	.13	4		1.2	
27	8.6		8.8		3.5		1	
28	7.5		8.6		3		1	
29	6.5		7.8		2.5		1.1	
30	5.5		7.1		2		1.4	
31			6.8		1.8			

MACON, MISS.—1896.

Black cretaceous prairie.

Day.	June.		July.		August.		September.	
	Uncultivated.	Rain.	Uncultivated.	Rain.	Uncultivated.	Rain.	Uncultivated.	Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1			22.2		22.6		19.8	
2			22.2		22.2		19.5	
3			22		21.4		19 8	
4			21.9		20.5		20.5	
5			21.8		19.9		20.6	
6			21.5		19.8		20.8	
7			21.4		19.7		20.5	
8			21.2		19.8		20	
9			21.3	Trace.	20		19.2	
10	22.5	0.02	21.4		20.2		18.6	
11	23.6		21.4		20		18.2	
12	25.2		21.4		19.8		17.6	
13	26		21.5		20		17.2	
14	26.8		21.3	Trace.	20.8		17.2	
15	27		21.4		21		17.5	
16	27		25	0.54	21		17.5	
17	27		25.7	1.42	20		17.2	
18	27		25.4		19	0.03	16.5	
19	27	.25	25		18.3	.13	15.6	
20	27.1	.76	24.5	.20	17.5		15.5	
21	27.2		24		17		16	
22	27.2		23.8		17.5		16.8	
23	27		23.8		17.8		17.2	
24	26.5		24		18.5		17.8	
25	26.2	.02	24.5		19.5	.52	18.5	
26	25.5		24		20.4		19	
27	25		23.8		20.8		20	
28	24.4		23.5		21		20.8	
29	23.5		23.4		21		21.8	0.31
30	22.6		23.2		20.2			
31			23		20			

GREENVILLE, MISS.—1896.

Black clay of the Mississippi bottom.

Day.	June.		July.		August.		September.	
	Uncultivated.	Rain.	Uncultivated.	Rain.	Uncultivated.	Rain.	Uncultivated.	Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1	21		18.5		18.2		20	
2	21		18.5		18.3		20	
3	20.4		19.1		18		20.2	
4	20		19.8		18		19.6	
5	20.5	0.04	19.8	0.03	18.1		18.5	
6	21	.06	19.7		18.3		17	
7	21	.03	19.6		18.2		18.2	
8	21.2		19.5		17.5		19.2	
9	21.9	.21	19.5		16.9		19.6	
10	22		19.6	.04	16.9		19.9	
11	22		20		16.9		19.8	Trace.
12	22		19.9		17		19.8	
13	21.8		19.8		17	0.01	19.8	
14	21.7		19.6		17		19.4	0.10
15	22		19.1		17	.10	19	
16	22.2	.17	18.5		17		18.6	
17	22.4		18.2		17		18.2	
18	22.6	Trace.	18.2		16.8		17.9	
19	22.8		18.9	.51	16.5	.11	17.5	Trace.
20	23		19.5	.11	16.5		17.2	
21	23.8		18		16.5	.01	17	
22	23.8		17.3	.15	17		16.5	
23	23		17		17.5	.32	16.5	
24	21.5	.01	17.5		18	.45	17.5	
25	20.5	.12	18		19		19.5	.42
26	20.2		18.4		19.6	.83	21.5	
27	20.2		18.4		20.2		23	.32
28	20.8	Trace.	18.5		20.8		21.5	
29	20.5		18.5		20.8		21	
30	19.8		18.4		20.6		20.8	
31			18.2		20.5			

PARIS, TEX.—1896.

Black waxy soil.

Day.	June.		July.		August.		September.	
	Uncultivated.	Rain.	Uncultivated.	Rain.	Uncultivated.	Rain.	Uncultivated.	Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1	25.1	....	17	0.03	15.2	....	14	....
2	24	....	17.2	....	14.5	....	14.2	....
3	23.5	....	16.6	....	14	0.23	14.8	....
4	23.6	....	16.4	.35	14.2	....	15.5	....
5	25.5	....	16.3	.03	14.5	....	16	....
6	27	....	16.4	....	14.2	....	16	....
7	26.4	....	16.5	....	14	....	15.8	....
8	25.8	0.29	16.8	....	13.8	....	15.8	....
9	24	....	17 5	....	13.7	....	15.8	....
10	22.5	....	18	.10	13.8	....	15.7	....
11	21	....	19	....	15	....	15	....
12	19.5	....	20	.17	16.5	.41	13.7	....
13	18.8	....	19.8	....	15.8	....	13	....
14	18.7	....	17.5	.10	15	....	12.8	....
15	19.5	....	16.3	....	14.5	....	12.3	....
16	20	....	15.4	....	13.9	....	12.2	....
17	20.3	....	15.2	....	13.8	....	12.3	....
18	19.5	....	15.6	....	13.5	....	12.4	....
19	19.5	....	16	....	13.8	.01	20	Rain.
20	19.5	....	15.5	....	13.5	....	18	0.55
21	19.5	....	14.6	....	13.4	....	15.6	....
22	19.5	....	14.7	....	13.8	....	14.5	.04
23	19.6	....	15	....	18	.91	14.4	....
24	20.5	....	15	....	17.8	....	16.5	....
25	21.6	....	14.5	....	17	....	18.5	....
26	21.6	....	13.8	....	16.5	....	19.4	....
27	20.8	....	13.8	....	15.9	....	18	....
28	20	....	13.5	....	15.5	....	18.5	....
29	19.3	....	13.2	....	15	....	18	....
30	18.4	.03	13.4	....	14.5	....	18	....
31	....	....	14.5	....	14.2	....	....	....

COLBY, KANS.—1896.

Prairie land.

Day.	June.					July.				
	Prairie sod.	Cultivated.	Subsoiled.	Irrigated.	Rain.	Prairie sod.	Cultivated.	Subsoiled.	Irrigated.	Rain.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Inch*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Inch.*
1	10.5	20	22	25.4	....	11.2	20.8	22.5	24.5	....
2	10.8	21.6	21.6	25.2	....	11.2	18.2	22.4	23.5	....
3	11	22.2	21	25	0.35	10.8	16.8	22.2	22.8	....
4	10.8	22	20	24.5	....	10.4	17.4	22	22.5	....
5	10.8	21.4	20.2	23.5	....	9.6	18	20.6	21.5	....
6	10	21	20.8	22.5	....	9	18.6	19.5	20.5	....
7	9.8	21.2	21	21.8	....	8.8	18.8	18.6	20.2	....
8	9.6	21.6	20.8	21	....	8.8	19.6	18	20.5	0.03
9	9.5	21.2	20	21.5	....	9.5	19.6	17.8	20.8	....
10	9.5	21	19.8	21.6	....	8.2	19	18	21	....
11	9.4	20.6	20	21.5	....	8	18.6	18	20.8	....
12	[illegible]	19	18	20.6	....	[illegible]	18.5	18	20.8	....
13	8.5	17	17	20.4	....	8	18.4	17.6	21.4	....
14	8.2	15.5	17.2	20.4	....	7.8	17	17	21	....
15	8.2	14.8	17.2	20.5	.03	7.6	17.5	16.8	20	....
16	8.3	17	18	20.6	.11	7.5	17.5	16.8	18.4	....
17	8.6	21	20	21	....	7.4	18	16.8	18.2	....
18	12	25	23	30	1.45	7.5	18.5	17	19.2	....
19	11.6	22.4	22.5	25.5	....	7.5	18.8	17.5	19.8	....
20	11	21	21.8	23.5	.28	7.6	18.8	18	19.8	....
21	10.8	20.8	21.6	22 6	....	7.8	18	18.5	19.5	....
22	10.8	22	22.5	22.8	....	8.4	17	19	19.4	.50
23	11.6	23	23.5	23.5	.50	8.6	16.6	19	19	....
24	13.5	24.9	24.5	24.5	....	8.6	17.5	18.5	17 2	.07
25	15	24.8	25	25.5	1.38	8	17.8	18.2	15	....
26	14.6	25.2	25.4	25.6	....	8	18.5	18.5	17.8	....
27	14	24.5	24.5	25	....	10.5	24	19.5	22.5	1.08
28	13	23.8	23.5	24.2	....	10.5	22.6	17	21.5	.12
29	12.5	25	25.2	25.5	.55	9.2	21.8	14.8	20	....
30	11.6	23.5	23.8	24.6	.03	9.2	21.2	15	19.8	....
31	....	....	....	....	....	9.5	21	16	19.6	.20

COLBY, KANS.—1896—Continued.

Prairie land.

Day.	August.					September.				
	Prairie sod.	Culti-vated.	Sub-soiled.	Irri-gated.	Rain.	Prairie sod.	Culti-vated.	Sub-soiled.	Irri-gated.	Rain.
	Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Inch.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Inch.*
1	10	20.5	17.5	18.9	....	9.5	19.4	18.5	18.5	....
2	9	19.5	18	18	....	9.8	18.9	20	17.5	....
3	7.8	18.6	17.9	17.3	....	10	18.8	19.9	16.8	....
4	7.6	18.3	17.8	17.3	....	9.5	20	19.6	16.8	....
5	8.8	21.6	22.1	23	0.70	9.2	21	20	18.5	....
6	8.9	21.4	21.8	22	....	9.2	21.1	19.6	20.4	....
7	8.5	20.5	20.8	20	....	9.1	21	19.4	20.3	....
8	8.1	19.5	20	17.5	....	9.2	20.5	19.4	19.8	....
9	7.8	17.5	19.8	15.9	....	9.3	20.5	19.5	20.2	....
10	7.9	16.2	19.2	15.6	....	13	24.5	23	23.5	0.61
11	[illegible]	16.1	18.8	15.8	....	12.5	23.5	22.5	22.8	....
12	8.1	16.7	18.5	16.2	....	11.5	22.8	21.9	22.4	.04
13	8.2	17	18.4	16.5	.21	11.5	23	21.9	22.4	.10
14	8.4	17.2	18.3	16.8	....	12.2	26	25	24.4	.47
15	8.3	18.6	18.3	17	....	12.6	24	23.8	22	....
16	8.3	19.4	18.3	17.4	.07	13.4	23	23	20.2	....
17	8.2	19.5	18.6	18.2	....	13.6	23.8	24.3	19.8	....
18	8.6	20	19.3	18.3	.17	14.2	24	25	20.3	.25
19	9.2	20.5	18.1	17	.06	14.2	23	23.5	20	....
20	9	20.5	18.5	16.1	....	13.8	22.4	21.5	19.5	....
21	9	20.4	18.5	16.3	.04	13.5	21.8	20.6	19	....
22	12.4	25	23	22.4	1.55	13.2	22	20.6	19.1	....
23	12	24.4	21.6	18.5	....	12.8	23	21.6	20.8	....
24	11.5	23.6	20	18	....	12.5	23.4	21.8	21.4	....
25	10.9	23.2	18.5	18.6	....	11.8	23	21.6	21.3	....
26	10.8	23	17	19.8	....	11.5	22	20.9	20.5	....
27	11	22.8	16.5	19.8	....	11	21.5	20.4	19.4	....
28	11	21.8	16.5	19.6	....	10.8	21.4	20.6	18.5	....
29	10.5	21	17	20.4	....	10.6	21.5	21	17	....
30	9.9	20.8	18.2	20.3	....	9.6	21.5	21	16.2	....
31	9.7	20.2	18.2	19.5	....	....	....	....	....	....

March, 1896. MARDELA SPRINGS, MD. April, 1896.

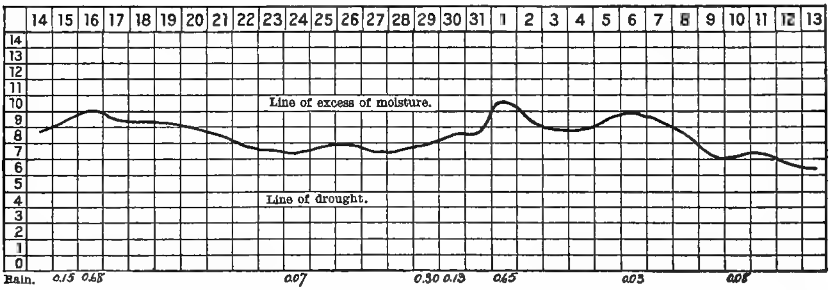


Diagram illustrating favorable conditions in the early truck land at Mardela Springs, Md., in the early spring.

July. MARDELA SPRINGS, MD. August.

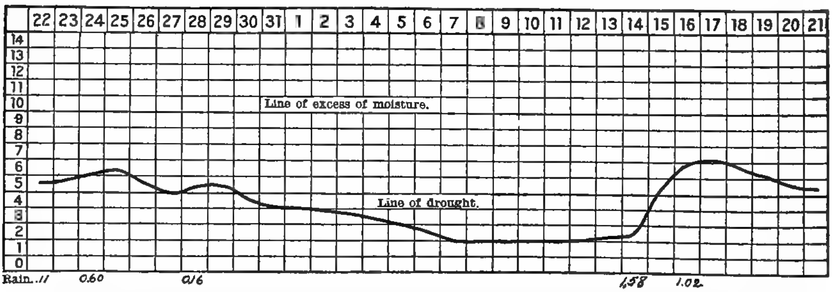
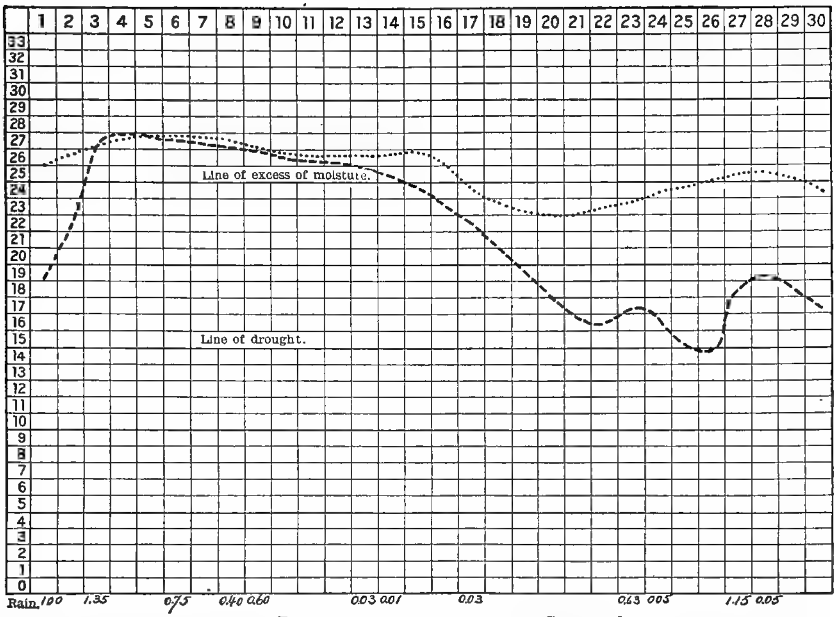


Diagram illustrating severe drought which greatly injured corn and such other crops as were growing in this early truck soil during July and August.

LEXINGTON, KY.

June, 1896.

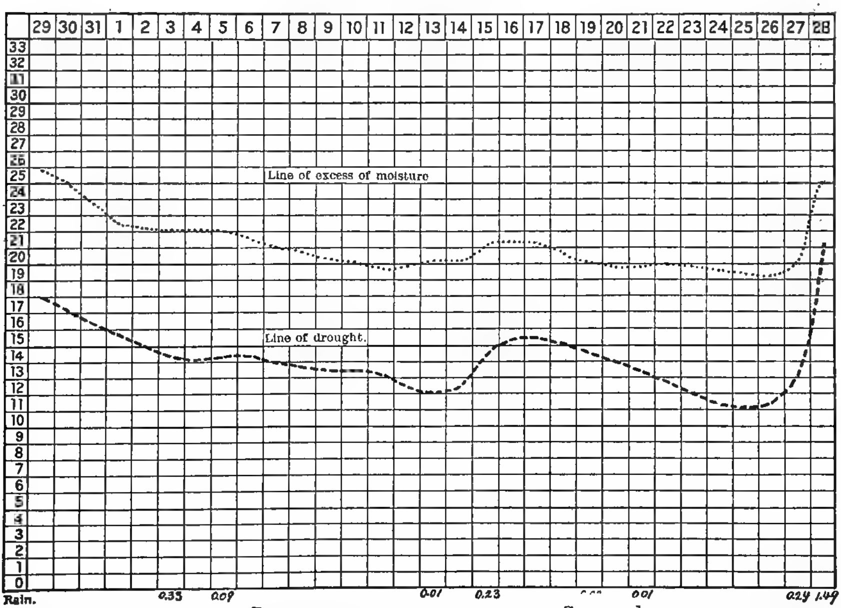


...... Bare. ...... Grass sod.

Diagram illustrating a wet period during the early part of June in the Trenton limestone—Kentucky bluegrass—land at Lexington, Ky.

LEXINGTON, KY.

August 29–September 18, 1896.



...... Bare. ...... Grass sod.

Diagram illustrating dry period during month of September in the Trenton limestone—Kentucky bluegrass—land at Lexington, Ky.

ST. MATTHEWS, S. C.

June, 1896.

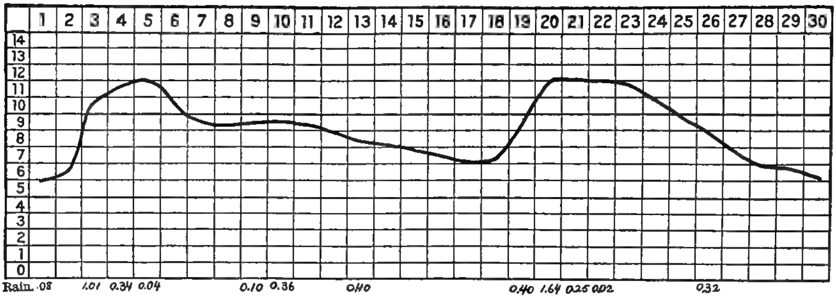


Diagram illustrating a favorable season for growing cotton in the Red Hill formation at St. Matthews, S. C.

ST. MATTHEWS, S. C.

September, 1896.

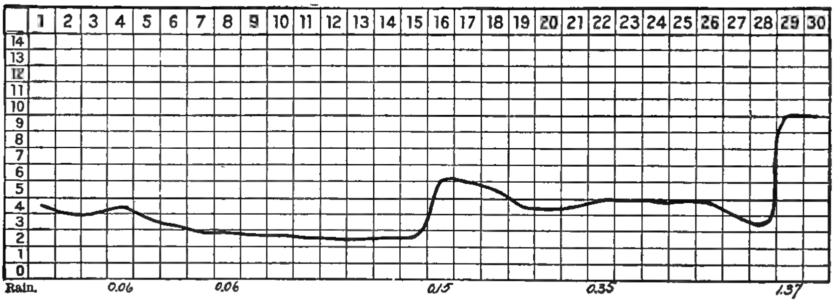


Diagram illustrating a favorable season for the ripening and picking of cotton in the Red Hill formation at St. Matthews, S. C.

UNION SPRINGS, ALA.

June, 1896.

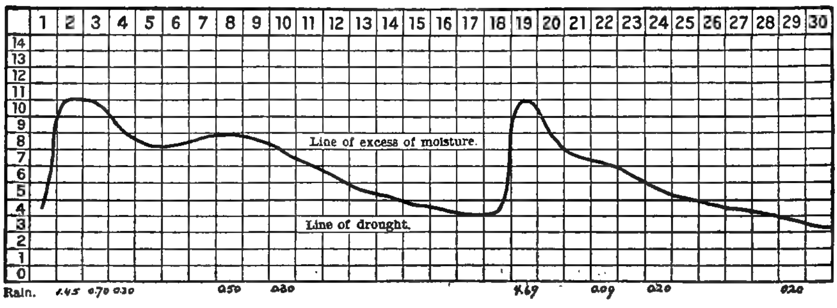


Diagram illustrating wet and favorable periods for growing cotton in the sandy cretaceous lands of Union Springs, Ala.

UNION SPRINGS, ALA.

September, 1896.

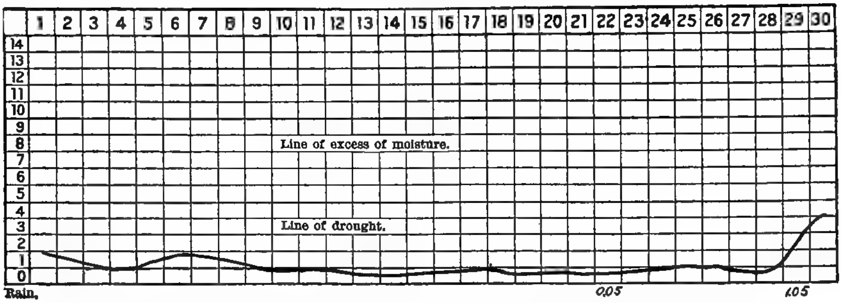


Diagram illustrating drought in the sandy cretaceous lands of Union Springs, Ala.

MACON, MISS.

July, 1896.

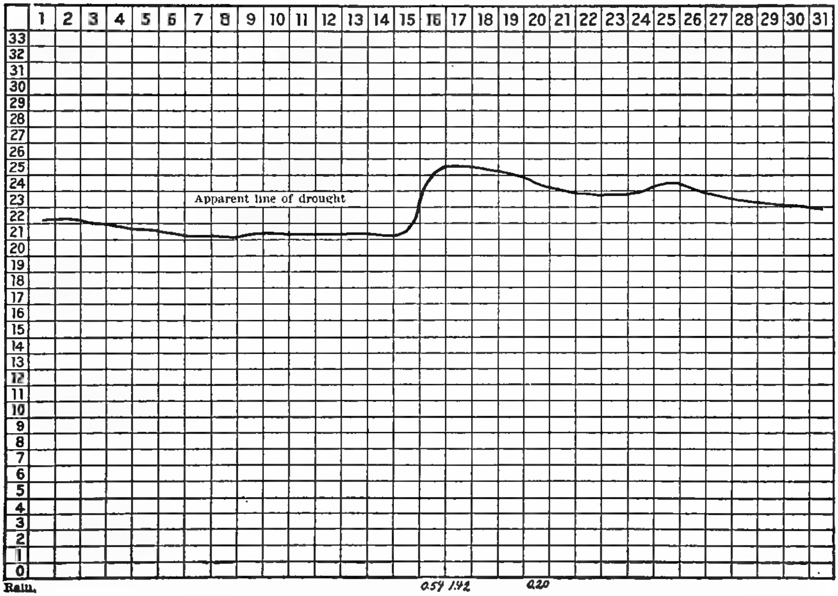


Diagram illustrating dry period in the black cretaceous prairie land at Macon, Miss.

GREENVILLE, MISS.

June, 1896.

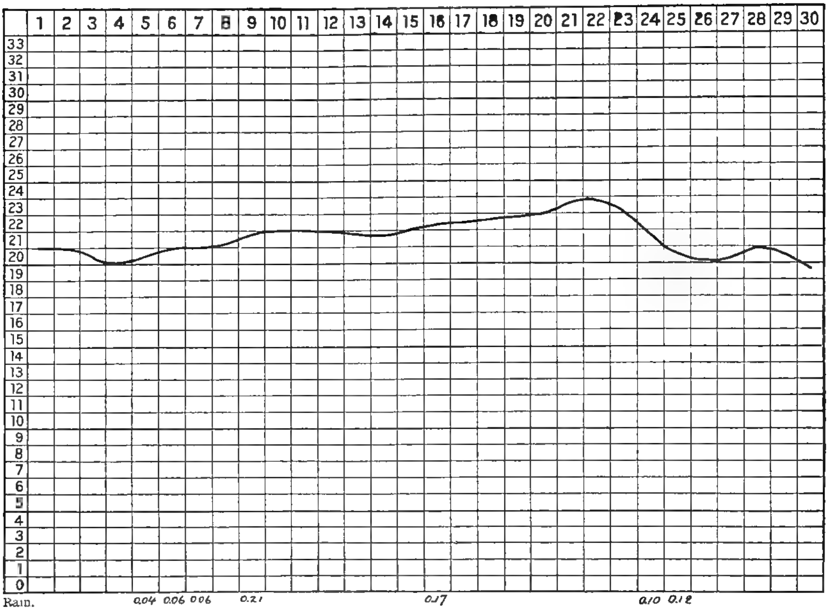


Diagram illustrating a dry period in the rich black clay lands of the Mississippi bottom. Twenty per cent of moisture is not sufficient to supply the needs of the crop on this land.

PARIS, TEX.

June, 1896.

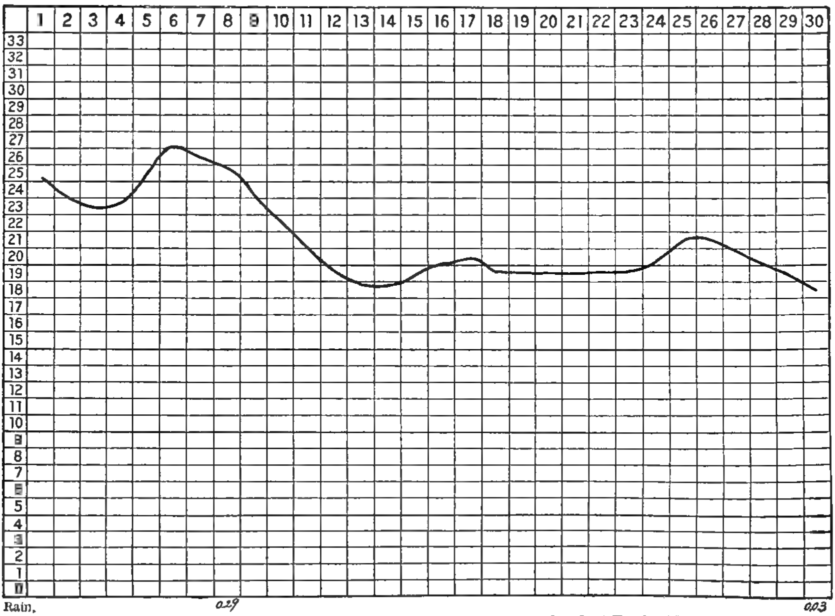
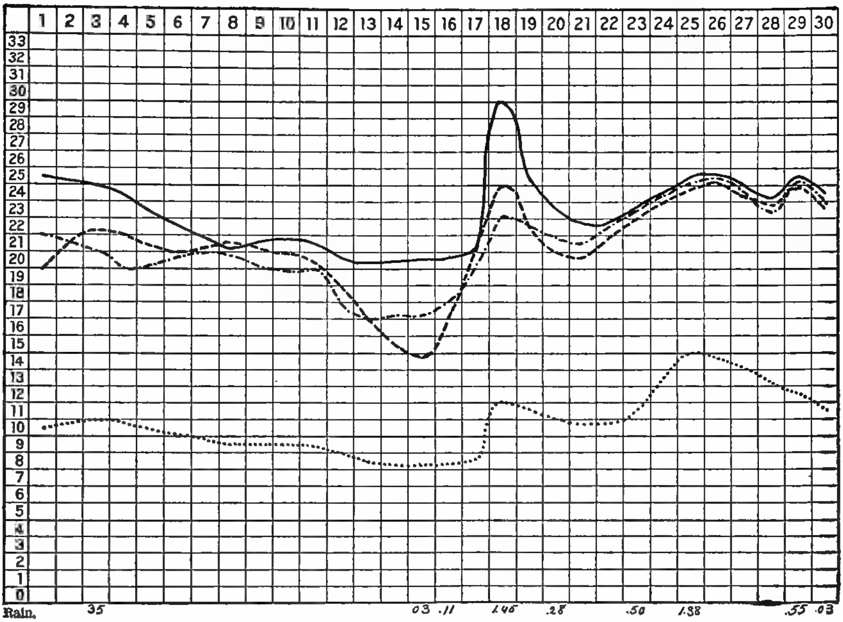


Diagram illustrating dry period in the black waxy land at Paris, Tex.

COLBY, KANS.

June, 1896.



...... Prairie sod. ...... Ordinary cultivation. -.-.-. Subsoiled. ——— Irrigated.

Influence of cultivation on moisture content of soils at Colby, Kans.

BULLETIN No. 10. S. 12.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF SOILS.

THE MECHANICS OF SOIL MOISTURE.

BY

LYMAN J. BRIGGS,
PHYSICIST, DIVISION OF SOILS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1897.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS,
Washington, D. C., September 1, 1897.

SIR: I have the honor to transmit herewith a paper upon the Mechanics of Soil Moisture, prepared by Mr. Lyman J. Briggs, physicist of this Division. The subject is necessarily treated in a technical way in order that it may be clearly understood by the student of agricultural science. It explains, however, more fully and clearly than ever before the actual cause of the capillary movement of water in soils and gives a much clearer knowledge of the laws and principles governing that movement than we have ever possessed. This is a subject of vast practical importance to the agriculturist, for the relation of his soils to water largely determines the class of crops which can be successfully grown upon them.

This paper is a valuable contribution to science, and I recommend that it be published as Bulletin No. 10 of this Division.

Respectfully,

MILTON WHITNEY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

THE MECHANICS OF SOIL MOISTURE.

INTRODUCTION.

It is intended in this bulletin to present the application of certain dynamical principles to the problems attending the movement and retention of soil moisture. Among these problems may be mentioned the capacity of a soil for water, the adjustment of water between a dry and a wet soil, the relation of texture, structure, and temperature to the water capacity, and the effect of fertilizers upon the water content of a soil.

The extreme complexity of the texture and structure of soils renders very difficult any rigorous analysis of the phenomena connected with the movement of soil moisture. There are, however, two conceptions of the soil which have been productive of good results. One is to consider the soil as made up of very fine particles without regard to the form of the particles or capillary spaces, the only condition being that the interstitial spaces are so small that the amount of interstitial space represented on any small section taken in any direction through the soil should be practically constant. Such a structure has been assumed by Dr. Katao[1] as the basis of an extensive memoir on the movement of water in soils. In the other conception of the soil the particles are assumed to be of some simple geometrical form, such as the sphere. By means of different arrangements of these spherical particles, structures having different amounts of interstitial space may be obtained. A calculation of the interstitial space for several arrangements has been given by Soyka,[2] and a comparison with the structure of typical soils was made later by Professor Whitney.[3]

While the principles that will be developed here are independent of the structure of the soil, the various arrangements of the soil grains which are set forth in the last form of structure referred to will be used to illustrate the principles and forces involved.

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[1] Ueber die Wasserbewegung in Boden. Bul. of College of Agriculture, Imperial University of Japan, vol. 3, No. 1, 1897.

[2] Forschungen auf dem Gebiete der Agrikultur-physik, B. 8, S. 1, 1885.

[3] Agricultural Science, vol. 3, p. 199, 1889.

PROPERTIES OF WATER AFFECTING ITS RETENTION AND MOVEMENT IN THE SOIL.

The water contained in a soil may be considered to be of three kinds—gravitation water, capillary water, and hygroscopic water. Gravitation water is that portion which is in excess of the amount which the soil is able to retain under existing conditions, and is consequently free to drain away. The capillary water is that part which would be retained in the capillary spaces under these conditions, and which is capable of movement through capillary action. The hygroscopic water is that found on the surface of the grains, which is not capable of movement through the action of gravity or capillary forces.

The maximum amount of water which a given soil may contain depends upon the resultant effect of the two forces—gravitation and surface tension. The force due to gravity is proportional to the mass of the liquid considered, and is always directed vertically downward. In other words, it is the weight of the liquid. This mass of liquid would therefore leave the soil if not opposed by the action of some other force, the vertical component of which acting along the same line as the force of gravity must be equal to it and opposite in direction. The effective part of this force and the manner of its application, which is of the greatest importance in determining the movement of water in a soil, will be considered later.

GRAVITATION OF WATER.

When a column of soil is saturated with water, its lower end being left in such a manner that water can escape, a gradual draining of the soil takes place. The rate of flow of this water gradually becomes less and less until finally it ceases. The amount of water which thus leaves the soil under the action of the force of gravity would be gravitation water, while that remaining in the capillary spaces of the soil would be capillary water.

There is no sharply-drawn line between these two quantities of water. The relative proportion depends, among other factors, upon the texture and structure of the soil, the surface tension of the soil water, the temperature, and the length of the column of soil considered. The importance of this last factor can be shown from the following considerations: Suppose we have 100 cubic inches of soil packed into 100 cubical boxes without bottom or top, each containing 1 cubic inch. Suppose the soil in each box to be saturated with water. There will be a free water surface at the top and at the bottom of each box. By means of forces existing in these surfaces the water in each cube is enabled to overcome the attraction of gravity, so that each cube is able to retain an amount of water equal to that necessary to produce saturation. In this case, therefore, there is no gravitation water. Suppose now that these cubical boxes are built up in a vertical column 100 inches high. The water surfaces previously existing at the top and bottom, respectively, of two cubes now disappear when one cube is placed on top of the other. Instead of having 200 surfaces as before, we now have only two surfaces, and they are called upon to support a column of water one hundred times as high as before. This they are unable to do, and water begins to drip from the lower surface. This water, which was previously what we have termed capillary, now becomes gravitational in its nature, due simply to a change in the length of the column. If the water in the soil was held in vertical capillary tubes running throughout the length of the column the water in each tube would simply fall until the two surfaces were able to support the weight of the liquid. In the soil, however, we have a different condition. As the water begins to leave the upper part of the column new surfaces are developed *within* the soil. As the water continues to drain away, these surfaces become more efficient in a way which will be explained later, and finally there comes a time when the opposing force exerted by these surfaces is sufficient to balance the weight of the liquid and the drainage ceases.

As an example of the displacement of water toward the bottom of a vertical column of soil, it is of interest to consider some experiments by Professor King,[1] who showed that for coarse sands this displacement is very marked. A vertical tube, 42 inches in length, filled with sand, continued to discharge water at its lower end for forty days after saturation. At the end of that period the top 6 inches of soil contained but 2 per cent of water, while the bottom 6 inches averaged 18 per cent. These results were in a general way corroborated by actual field observations on an area protected from precipitation and evaporation. No experiments were made on soils of a finer texture. It will be shown later that in such soils the movement would probably be much less marked.

SURFACE TENSION.

It has been pointed out that the force exerted on a liquid through gravity varies only with the mass of the liquid. This force can therefore change in value only when the mass of the liquid varies. From this it follows that any movement of water which takes place after equilibrium has been once established must be brought about through a change in the amount of water present in the soil or through a change in the force opposing gravitation. It is therefore of importance to consider the nature of this opposing force which we call surface tension.

The phenomenon of surface tension is due to the existence of molecular forces. In a suspended drop of water, for example, the particles in the interior of the liquid are attracted equally in all directions by the other particles of the liquid. The resultant attraction on any particle in the interior is therefore zero, and it is free to move through the liquid. A particle on the surface of the drop, on the contrary, is not attracted equally on all sides, since the molecules of the gas surround-

[1] Fluctuations in the Level and Rate of Movement of Ground Water. F. H. King, U. S. Dept. of Agriculture Bul. No. 5, Weather Bureau, p. 25.

ing the drop exert less attraction upon the particle than is exerted by the particles of the liquid. The resultant attraction is therefore inward, along a line perpendicular to the surface of the liquid at that point. Now, the equations representing the behavior of the drop under the action of these forces are identical with those obtained if we imagine the drop inclosed in a water-tight membrane having a uniform tension. The action of the drop is therefore the same as if this imaginary membrane actually existed, and what we call surface tension is the tension that this ideal membrane would have to possess in order to produce the observed phenomena. This ideal membrane differs from all material membranes in that its tension does not change when the surface is increased. When the surface is extended, particles which were formerly in the interior are brought to the surface, so that the number of particles per unit of area of the surface always remains the same. The surface tension is also practically independent of the form of the surface. The mathematical theory indicates a very slight increase where the mean curvature is concave, and a slight decrease where it is convex. This difference is too small to be verified experimentally, but is of interest in connection with the fact that evaporation will take place from the convex surface at the same time that condensation is taking place on the concave surface. This in itself, then, must furnish a means of gradual adjustment of the water in the capillary spaces of a soil.

It is of importance here to distinguish clearly between surface tension and the effective force of a film. It has just been stated that the surface tension or the energy per unit area in the film is independent of the form and extent of the surface. The effective force or the pressure of the film, on the other hand, is dependent upon both the form and extent of the surface as well as upon the surface tension. This subject will be discussed more fully later.

When a drop of a liquid is placed upon the horizontal surface of a solid, it either rapidly spreads out upon the surface in a thin film, as a drop of water on a clean glass plate, or else remains in the form of a drop, with as little surface as possible in contact with the solid, as in the case of mercury on glass. If we know the surface tensions of the three surfaces which separate the solid and liquid, solid and gas, and liquid and gas, respectively, the action of the drop can be anticipated. This arises from the following considerations: Let the solid, liquid, and gaseous media in contact be represented by s, l, and g, respectively. The surfaces separating these three media will meet in a line. Through any point in this line pass a plane perpendicular to the line, and let this section be represented by the plane of the paper in fig. 1.

At the point O there exist three forces equal in magnitude to the tensions of the surfaces of separation and directed along lines tangent to the surfaces at that point. In order that the system may be in equilibrium it is necessary that each of these forces shall exactly balance the resultant force of the other two. Let the vectors in the figure represent the direction and magnitude of these three forces. If these forces are in equilibrium, then lines drawn parallel to the vectors and equal to them in length will form the three sides of a triangle. The exterior angles of this triangle represent the angles between the surfaces of separation of the three substances.

If a system is not in equilibrium, an adjustment must take place through change in the *direction* of the vectors, since their magnitude remains constant. Consequently, the surfaces tend to change until the necessary angle is obtained. In general, if the tension of the solid-liquid surface is greater than the sum of the tensions of the other surfaces, the liquid will gather itself up in a drop, as in the case of

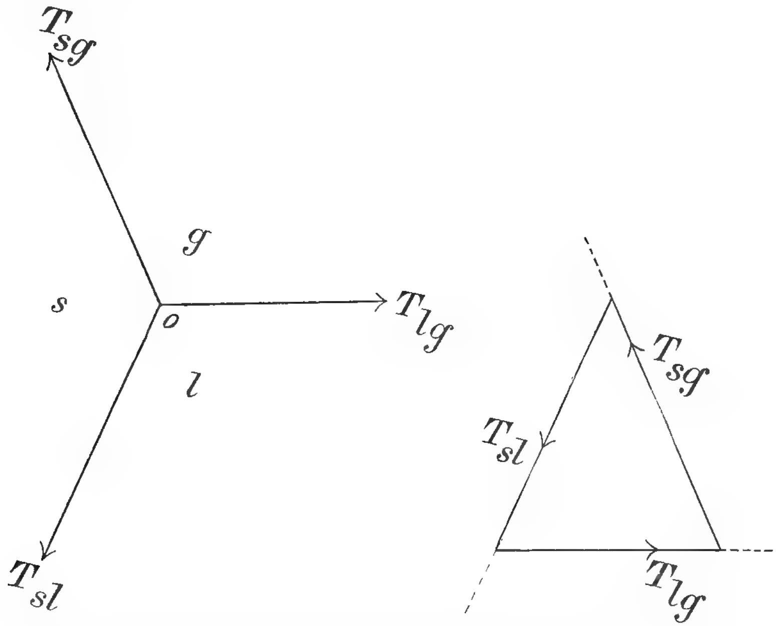

FIG. 1.—Condition of equilibrium among the surface tensions of three media in contact.

mercury. If, however, the solid-gas surface has a tension greater than the resultant of the other two, the liquid tends to spread out over the surface of the solid. If the tension of the liquid-gas surface is greater than the difference between the tensions of the liquid-solid and the gas-solid, then the liquid finally reaches a condition of equilibrium. The angle between the liquid-solid and the liquid gas surfaces is known as the capillary angle.

In the case of oil on water the tension of the water-air surface is greater than the sum of the other two tensions, so that no triangle of forces can be formed. The system is therefore unstable and the oil spreads out on the water indefinitely in a film until it ceases to have the same physical properties as the liquid. Lord Rayleigh has made use of the minimum thickness of this film as the basis of an estimation of the maximum diameter of oil molecules.

With the exception of mercury, water possesses a higher surface tension than any other substance which is liquid at ordinary temperatures. The surface tension of water[1] expressed in dynes per centimeter is 75.6 at 0° C. and 72.1 at 25°. The temperature coefficient is thus about —0.14 dynes per degree Centigrade. The surface tension of most aqueous solutions of salt is higher than that of water, and the surface tension increases with the concentration of the solution, as is shown in the following table:

Surface tension of solutions of salts in water.

Salt in solution.	Density.	Concentration. *a*	Temperature.	Surface tension.
			C.	*Dynes per cm.*
KCl	1.170	25	15-16	82.8
KCl	1.101	15	15-16	80.1
KCl	1.046	7	15-16	78.2
NaCl	1.193	25	20	85.8
NaCl	1.107	15	20	80.5
NaCl	1.036	5	20	77.6
K_2CO_3	1.357	35	15-16	90.9
K_2CO_3	1.157	16	15-16	81.8
K_2CO_3	1.040	5	15-16	77.5
KNO_3	1.126	19	14	78.9
KNO_3	1.047	7	14	77.6
$MgSO_4$	1.274	24	15-16	83.2
$MgSO_4$	1.068	6	15-16	77.8

a Approximate weight of the dissolved substance in 100 parts by weight of the solution.

Most organic substances found in soils, especially those of an oily nature, being insoluble in water and hence most evident on the surface, lower the surface tension to a marked degree. The tension of soil extracts, therefore, is generally much lower than that of pure water, in spite of the presence of dissolved salts.

VISCOSITY.

It has been pointed out that the two great factors in determining the movement and retention of soil moisture are gravitation and surface tension. We have now to consider a modifying influence which is exerted upon these factors through the viscosity, or internal friction, of the liquid upon which these forces are acting, the effect of which is to retard the establishment of equilibrium. The relative viscosity of fluids may be determined by their rate of flow through capillary tubes under uniform conditions. Viscosity is generally expressed in terms of the coefficient of viscosity, which is numerically equal to the force necessary to maintain a flow of a layer of unit area past another layer of unit area with unit relative velocity. This coefficient is influenced by temperature to a considerable extent. If we take the viscosity[2] of water at 0° C.

[1] Smithsonian Physical Tables, 1896, p. 128. These values are a mean of the results obtained by Lord Rayleigh from the wave length of ripples (Phil. Mag., 1890), and by Hall from the direct measurement of the tension of a flat film (Phil. Mag., 1893).

[2] Smithsonian Physical Tables, 1896, p. 136.

to be 100, the viscosity at 25° C. is 50, at 30° is 45, and at 50° about 31. This great variation in viscosity with change of temperature is illustrated in the flow of water through soils, which King[1] found in his leaching experiments but failed to explain. He observed the rate of flow at 9° C. to be 6.15 grams per minute, while the rate of flow at 32.5° C. was 10.54 grams per minute. The ratio of the two rates of flow is 1.71. Now the viscosity of water at 9° C. as compared with water at 0° C. is 75.6, and 32.5° is 42.5. The ratio of the two viscosities is 1.77, which agrees very well with the ratio of the observed rates of flow.

The viscosity of gases in opposition to that of fluids increases with increase of temperature. Air, which is largely used in making so-called "permeability" determinations of soils, has a viscosity of 0.00017 $(1+.00273\ t)$. An increase in temperature of 40° C. would therefore cause the coefficient of viscosity of air to increase one-tenth of its amount. This evidently should always be taken into consideration in determining the physical character of a soil. G. Ammon,[2] in using air to determine the relative permeability of soils, and neglecting the change in viscosity with temperature, found that the permeability of a soil decreased with increase of temperature. The rate of flow of air at the higher temperatures as observed by him, when corrected for viscosity, agrees with the flow observed for the lowest temperatures within the errors of experiment.

HYGROSCOPIC STATE.

Most solid substances when exposed to ordinary atmospheric conditions condense upon their surfaces a slight amount of moisture. This moisture adheres with remarkable tenacity, and can be completely driven off only by prolonged heating at temperatures above the boiling point of water. In some soils the presence of hygroscopic moisture is very marked, on account of the large amount of surface presented by the soil grains. Air-dried samples, in which all visible evidences of moisture have disappeared, still contain under ordinary atmospheric conditions moisture in the hygroscopic form, amounting in some soils to 8 to 10 per cent of the dry weight.

The table following, taken from a paper by Loughridge,[3] illustrates the variation of hygroscopic moisture in soils of different texture. These values were obtained by exposing the soil in a very thin layer to a saturated atmosphere, kept at a constant temperature, for a period of twenty-four hours.

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[1] U. S. Weather Bureau Bul. No. 5, 1892, p. 66.

[2] Forschungen auf dem Gebiete der Agrikultur-Physik, B. 3, S. 209.

[3] Investigations in Soil Physics.—R. H. Loughridge. Report of the California Experiment Station, 1892–93, p. 70.

Hygroscopic moisture of soils.

Name and character.	Hygroscopic moisture.	Mechanical analysis.		Chemical analysis.	
		Clay.	Clay to 0.25 mm.	Soluble silicates.	Ferric hydrate.
Clay:		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Black adobe	14.5	32.6	74.0	23.3	7.7
Red soil	14.2	24.8	57.1	54.0	9.5
Red mountain soil	13.7	52.2	67.9	26.9	29.7
Red volcanic soil	11.1	29.8	61.2	34.3	12.0
Alluvial soil	10.3	31.5	76.8	20.7	9.1
Alkali soil	2.6	26.1	54.0		
Loams:					
Sediment soil	9.2	12.1	55.6	25.1	7.3
Granitic soil	5.9	11.9	32.8	21.0	6.2
Plains soil	4.9	10.5	34.9	16.5	6.6
Sandy:					
Gila bottom soils	3.5	3.2	8.7	8.9	7.4
Sandy soil	1.2	2.6	8.9		
Do	.8	2.8	5.2		

Under the conditions employed in the determinations given in the table it is not improbable that water was condensed in some of the more minute capillary spaces. Lord Kelvin[1] has shown that such a minute capillary surface is capable of condensing moisture even when evaporation is taking place from a neighboring plane surface of water. Some capillary spaces might therefore be able to hold minute quantities of water under conditions which would remove the water from larger spaces. In this way we might have some water held in a soil by capillary action, under conditions which would seem to indicate that the water content must be purely hygroscopic in its nature.

The nature of this thin film which constitutes the hygroscopic moisture is not definitely known. It may extend uniformly over the surface of the grains independently of their form or nature; or it may be discontinuous, occurring only in spots on the surface and depending to some extent on the form and nature of the grain. It would seem justifiable to assume that the amount of moisture thus held is proportional to the surface of the grains, but this conclusion is supported only in a very general way by the results given in the investigation quoted, from which the above table was compiled. Loughridge remarks, in explanation of this, that the clays may be considered as very complex substances made up not only of particles in a very fine state of division, but combined with ferric, aluminic, silicic, and humic hydrates existing in the soil in greatly varied amounts. Even if the presence of these hydrates did not directly influence the hygroscopic water of a soil their decomposition at the high temperature which it is necessary to maintain in order to drive off the hygroscopic moisture would introduce a disturbing factor in the value of the hygroscopic water content. On the other hand, it must be remembered that a mechanical analysis of a soil gives only in a very general way an idea of the surface area of the grains in a soil, and that a soil exposed to a saturated atmosphere is apt to acquire considerable moisture which is not strictly hygroscopic. The

[1] Maxwell, Theory of Heat, p. 287.

relation of hygroscopic moisture to the relative surface area presented by different soils, determined by a method which depends directly upon the amount of surface, will be made the subject of a later investigation.

PROPERTIES OF FILMS.

Since the movement and adjustment of water among the soil grains depend upon forces whose action is the same as if a uniform tension existed in the water surfaces, it is very important to study the properties of these surfaces and their effectiveness under different conditions. Water is not a convenient substance to use in the experimental study of films, since its high surface tension and low superficial viscosity make the film unstable, except when very small surfaces are used. An ordinary soap solution, on the other hand—or better, a solution of oleate of soda to which a quantity of glycerin has been added—gives films of great stability and highly adapted to experiment.[1]

The most familiar form of a soap film is the spherical surface assumed by a bubble, as representing the least surface area under the given conditions. The fact that the bubble will contract and finally become a plane film across the end of the pipe shows that there is a tension in the film which produces a pressure upon the air inside the bubble. Suppose, now, that a large and a small bubble are connected by means of a short pipe of circular cross section. It might be expected that the large bubble would blow the smaller one out until the two were of equal size. On the contrary, the opposite takes place. The small bubble contracts until it becomes a film across the end of the pipe. This film, however, is not a plane as in the first case, since on one side there is the pressure due to the large bubble and on the other the atmospheric pressure. It will consequently assume a spherical surface identical with a segment of the large bubble, of which it in reality forms a part, separated from it by means of the pipe.

The action of the smaller bubble in blowing out the larger, or the pressure in the smaller bubble being greater than in the larger, might have been to some extent anticipated if we had considered more fully the plane film across the end of the open pipe. Suppose such a film stretched across a circular ring of wire. This film might be looked upon as part of the surface of a great bubble of infinite radius. Since the pressure on both sides of the film is the same, it follows that in such a bubble the pressure inside would equal the pressure outside. It is not necessary, therefore, for the film to exert any pressure in either direction in order to maintain the equilibrium of the system. For a plane surface or a sphere of infinite radius it is evident that the pressure of the film is zero.

Let us now consider a ring of smaller radius than the first, contain-

[1] For particulars in regard to the preparation of the soap solution, see Soap Bubbles, C. V. Boys, published by Young & Co., New York. This book also contains an account of many interesting and instructive experiments with films.

ing a segment of a bubble of such radius that the surface area of the segment is just equal to the surface area of the plane film held in the first ring. The surface energy is the same in the two cases. In the first case, however, it is directed in the plane of the ring, while in the latter case it can be divided into two portions, one of which acts in the plane of the ring and the other in a direction at right angles to this plane. This film, therefore, exerts a pressure, while the other does not, although both have the same energy. This pressure, therefore, evidently depends upon the form of the surface. This is of the greatest importance in connection with the problems relative to the movement of soil moisture. It is the form of the capillary surface which determines whether or not it is in equilibrium with other water surfaces in the soil—whether it shall expand or contract, advance or recede.

PRESSURE OF A FILM.

It has been shown that the pressure which a film is able to exert is dependent on the form of the film. It is now of interest and importance to determine in what way the pressure is related to the curvature of the film and to its surface tension, in order that the action of films under certain conditions in the soil may be determined.

Suppose a cylindrical film of radius r and pass a plane through it at right angles to the axis.[1] Suppose the section to be represented by the plane of the paper. (See fig. 2.) Let ab be a small portion of the section of the film thus formed. Let T represent the surface tension directed tangentially at a and b in the plane of the section, the film considered being taken of unit width perpendicular to this plane and of length ab.

The resultant of the two components of T is cd or P.

$$\text{Then } P=2T \sin \tfrac{1}{2}\,\theta$$

$$\text{Sin } \tfrac{1}{2}\,\theta=\frac{ab}{2r} \;\therefore\; P=T\,\frac{ab}{r}.$$

If $ab=1$, we have the unit area of surface and $P=\frac{T}{r}$; or the pressure varies directly as the surface tension and the curvature, the latter being the reciprocal of the radius. In general the pressure on any film at any point can be expressed by

$$P=T\left(\frac{1}{r_1}+\frac{1}{r_2}\right)$$

in which r_1 and r_2 represent the radii of curvature of the sections formed by passing two normal planes at right angles through the point.

For a sphere $r_1=r_2$, and we have $P=\frac{2T}{r}$ or the pressure of a spherical surface is twice the surface tension divided by the radius. It is now easy to understand why the smaller bubble blows the larger one out.

[1] In what follows, but one surface of the film is considered. Where two concentric surfaces exist, as in bubbles, the pressure would be doubled.

Since the surface tension is the same on both bubbles, if the smaller bubble is only one-half the diameter of the larger its internal pressure would be twice as much.

SURFACE OF NO PRESSURE.

It is evident from the equation that there are only two surfaces of revolution in which the pressure can be zero. For if we put P equal to zero it is necessary either that both r_1 and r_2 be equal to infinity, or that $r_1 = -r_2$ in order that the equation may be satisfied. The first case is satisfied by the plane, which is a sphere of infinite radius. A plane film therefore has no pressure. The other case is satisfied by the catenoid surface in which $r_1 = -r_2$, that is, in which the radii are numerically equal and on opposite sides of the film. This figure is of much importance in the consideration of films. It is generated by the revolution of the catenary curve (*catena*, chain) about its directrix. This curve is that represented by a chain or flexible cord of uniform weight hanging from two horizontal supports at a distance from each other less than the length of the cord. The equation is:

$$y = \frac{a}{2}\left(e^{\frac{x}{a}} - e^{-\frac{x}{a}}\right)$$

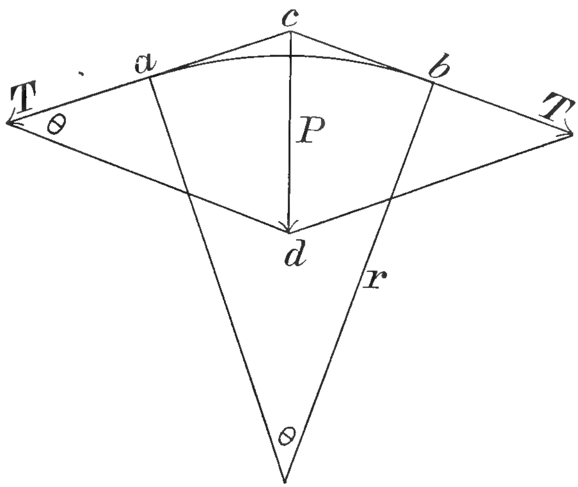

FIG. 2.—Pressure of a film.

in which a is the distance from the lowest point of the curve to the directrix, which is taken to coincide with the axis of x, and e is the base of the natural system of logarithms. It is evident that the curve is symmetrical about the axis of y and that its intercept on the axis of y is equal to the value of a chosen. This curve is illustrated in fig. 3, in which different forms are obtained by assigning different values to a. They represent the different positions assumed by a chain under different tensions, or by a film having different surface tensions.

One of the best examples of the catenoid is found in a soap film stretched between two equal circular rings of wire so placed that their planes are parallel and their edges bound a rectilinear cylinder. This can be easily prepared by wetting the rings in the soap solution and blowing a bubble upon them. The film inside each ring is then broken with a hot wire, after which the rings may be separated. Since the pressure is now the same on both sides of the film we have a surface of no pressure. This surface is stable only when the tangents to the catenary at its extremities intersect before reaching the axis of the figure. The accompanying illustration (fig. 4) is taken from a photograph of a film prepared in the manner described.

A section of the catenoid midway between the wire rings and parallel to them is a circle. A circle of this diameter if cut out from a piece of paper and held with its edge against the catenary would exactly fit the surface for a short distance each side of the center, or the surface is one of no curvature. Since the potential energy of any system always tends to reach its minimum, the film tends to contract to its smallest possible

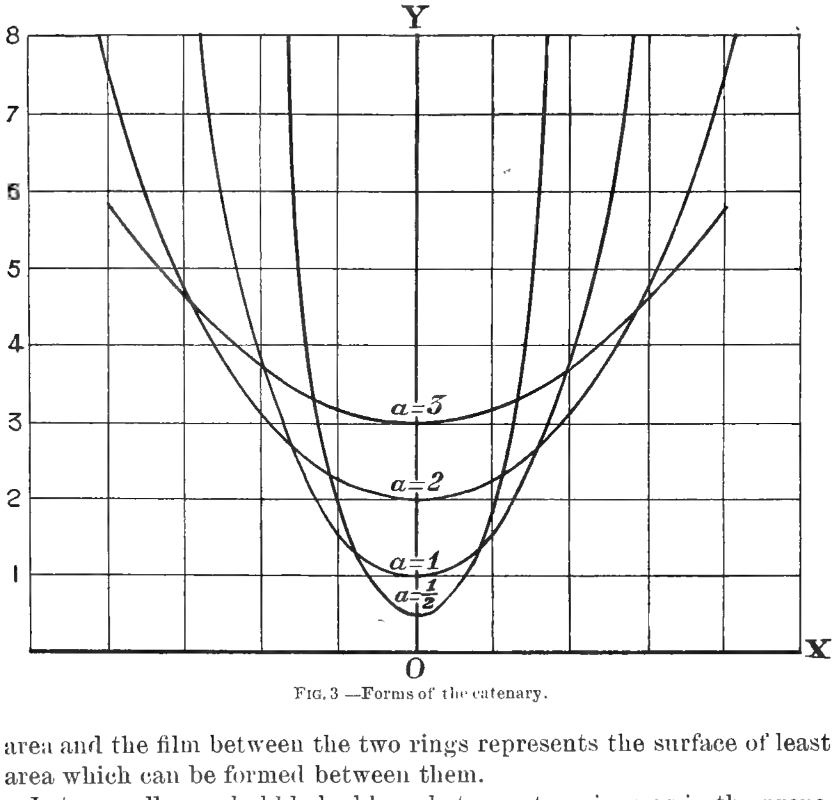

FIG. 3 —Forms of the catenary.

area and the film between the two rings represents the surface of least area which can be formed between them.

Let a small soap bubble be blown between two rings as in the preparation of the catenoid soap film. Now separate the rings until the film between the rings forms a cylinder with straight walls, as in fig. 5. The pressure inside the cylinder is evidently greater than the atmospheric pressure, as is shown by the bulging outward of the films inside the rings. In fact, from a measurement of the curvature of these spherical segments at the end of the cylinder, we find the pressure in the cylinder to be equal to that of a spherical bubble of twice the diameter of the cylinder.

Now insert the pipe in the cylinder through one of the ends and allow the pressure inside and out to become equalized. The films inside the rings become plane, since the plane is a surface of no pressure. The cylinder degenerates into a catenoid, also a surface of no pressure. Suppose now the pressure is reduced still more, so that the films inside the rings bulge inward, showing the pressure on the inside to be less than outside. This gives a surface having a more pronounced waist than the catenoid. It represents the form assumed by the free surface of a liquid between two solid surfaces, which it wets and is therefore called a capillary surface. This form of surface is therefore the one that is met with in the capillary space formed by the contact of two soil grains. The generating curve of a capillary surface is known as the "elastic curve," from its identity with the curve formed by a straight spring of uniform flexibility when its ends are acted upon by equal and opposite forces. Some of the forms assumed by this curve under different conditions can be easily obtained with a steel spring.[1]

FIG. 4.—Catenoidal film.

To summarize briefly, the pressure which a film may exert depends upon its surface tension and its form: (1) The pressure of the film may be inward, as in the case of the cylinder, indicated by the films inside the rings being forced outward; (2) the pressure may be zero, as in the case of the catenoid, the films inside the rings being plane; (3) the pressure may be outward, as in the case of surfaces generated by the elastic curve, the films within the ring being drawn inward.

FIG. 5.—Cylindrical film.

If the interior of two closed films of unequal size, both having a pressure inward and both free to move, are connected, the smaller film having the greater pressure will contract, forcing the larger film to expand. This is illustrated by two soap bubbles or by the coalescence of drops of mercury. If the two films have a pressure outward, the smaller film,

[1] For tracings obtained in this way see Thomson & Tait, Natural Philosophy, Part I, p. 148.

having the greater curvature, will expand until the two films become equal. This is what would take place in surfaces generated by the elastic curve—that is, capillary surfaces—if these surfaces were free to move, and is of the greatest importance in the adjustment of the water content of a soil among the capillary spaces.

FORM OF WATER SURFACE BETWEEN TWO SOIL GRAINS.

The manner in which water is held in a soil may now be considered. Suppose the soil grains to be momentarily separated so that no two grains are in contact. Each grain carries with it a small amount of moisture, which, through the agency of surface tension, spreads over the surface of the grain. Suppose now that two of these grains, which may be assumed spherical in form, are once more brought in contact. The water is drawn into the capillary space formed between the spheres and forms between the grains a capillary water surface.

The collection of a portion of the water previously distributed over the surface of the grains into this capillary space may be explained from a consideration of the curvature and pressure of the water surfaces, which will hereafter be designated as films. When the two spheres are brought in contact, the films in meeting form a surface of very great curvature having a pressure outward. Since the two films on the surface of the spheres have a pressure inward, the water moves rapidly toward the capillary space. As the new surface increases, its pressure becomes less and the movement of water becomes slower, finally ceasing when the pressure is not sufficient to overcome the resistance offered by the films.

The arrangement of the water between the spheres may also be considered from the standpoint of the potential energy of the system. It has been shown that a film between two rings assumes the form of the catenoid, as representing the least surface, and consequently the minimum potential energy. Therefore, any liquid surface held between two parallel planes will tend, so far as the conditions will admit, to approach the catenoid in form, which is the limiting form of the capillary surface. This is well illustrated by the ink between the blades of a right-line ruling pen. These parallel planes may be supposed to separate gradually as the amount of water increases, and this gives the condition on the spherical surfaces.

On the assumption that no evaporation can take place and that the spheres are entirely covered with moisture before being brought in contact, it follows that the spheres will still be covered after contact, although the film will be much thinner than before. The amount of diminution in the surface, due to the contact of the spheres, is evidently equal to the difference between the combined area of the original water surfaces and the combined area of the spherical segments outside the capillary surface, together with the area of the capillary surface. If the thickness of the original films on the spheres was small in comparison with their radii, the diminution in surface is practically equal to the difference between the combined areas of the spherical surfaces inclosed in the capillary space and the area of the inclosing capillary surface. If the equation of the capillary surface, which is too complex to be considered profitably here, is known, the area of the surface can be calculated and the change in potential energy determined.

ESTABLISHMENT OF EQUILIBRIUM BETWEEN TWO UNEQUAL MASSES OF CAPILLARY WATER.

Suppose the capillary spaces formed by several spheres in contact to contain different amounts of water. These spheres are supposed originally to have been covered with films and then brought in contact, so that water films will exist on all surfaces which are not submerged. Let one of these films connect the water held in two adjacent capillary spaces containing different quantities of water. This is illustrated

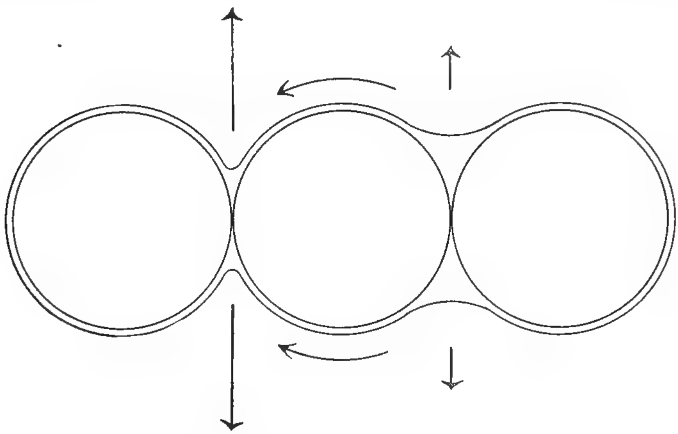

FIG. 6.—Adjustment of water between two capillary spaces.

diagrammatically in fig. 6, which represents a section through the centers of three spheres in contact.

Since the capillary spaces are similar in form, it follows from previous considerations that the surface of the smaller mass of water will have the greater curvature, and consequently the greater pressure outward. The direction and relative magnitude of the pressures of the two films taken within the section are represented by the length of arrows. Since the surface of the lesser mass of water exerts the greater pressure outward, water will move through the connecting film in the direction of the curved arrows from the greater to the lesser mass. This action will continue until the pressure becomes the same, which in this case takes place when the capillary spaces contain equal amounts of water, since the spaces are of the same form. In any case, equilibrium is reached when the two films attain the same curvature.

The rate at which this adjustment of water between two capillary spaces will take place depends upon the viscosity of the connecting film, the surface tension, and the difference in curvature of the films. The viscosity of the connecting film does not in any way interfere with the final adjustment of the water, but it retards to a greater or less degree the establishment of equilibrium. An increase in either the curvature or the surface tension causes an increase in pressure, as has been previously pointed out.

It is evident that this movement can be extended to any number of capillary spaces through any number of films, so that adjustment takes place over a large mass of soil when disturbing influences are introduced. This change takes place more or less slowly, according to the amount of water present in the soil. If the soil is nearly saturated, so that the films connecting the capillary spaces are short and thick and the capillary spaces themselves are not active, but little resistance is offered to the movement of water and the addition of water at the surface is quickly felt farther down. If, on the other hand, the soil contains but little water, the same amount of water added to the surface, while producing marked changes in the upper layers, will not be felt so quickly at the lower depths on account of the activity of the upper capillary spaces and the length and small cross section of the connecting films. But an adjustment of the water between the upper and lower capillary spaces takes place in this case also until equilibrium is gradually reached.

SALTS AS AFFECTING THE MOVEMENT OF WATER IN SOILS.

We have seen the importance of surface tension in opposing the gravitation of capillary water of soils. Any change in the surface tension of the soil moisture tends to bring about an adjustment of the water throughout the whole mass of soil. If the surface tension of the water in the upper layers of a soil is increased, water is drawn toward that point. Since the surface tension of most salt solutions is higher than that of water, and the surface tension increases with the concentration of the solution, it might be expected that any salt used as fertilizer a solution of which has a high surface tension would increase the amount of water in the soil.

It must be remembered, however, that the surface tension of solutions is very greatly decreased by the addition of very small quantities of certain organic substances produced through the decomposition of vegetable matter. This action is especially marked where there are present substances of an oily nature which do not go into solution, but spread out over the surface in an extremely thin film. Owing to such substances being continually produced by the decay of organic matter, the surface tension of the soil moisture is kept very low and could be only slightly influenced by the addition of salts. The application of substances to the soil for the purpose of changing its water content through a change in the surface tension, would not therefore necessarily be productive of marked results.

TEMPERATURE AS AFFECTING THE MOVEMENT OF WATER IN SOILS.

It was pointed out in a preceding section that the surface tension of water decreases with increase of temperature. Therefore if the bottom of a column of soil in which the water has attained a condition of equilibrium should be cooled, the surface tension of the lower strata would be raised and the water would be drawn toward the bottom, or if the lower strata should be heated the water would tend to move toward the top. The first method of procedure should give the most marked results, since the movement in this case is assisted by gravitation. A movement should also be secured by raising or lowering the temperature of the whole mass of soil uniformly. In the first case the water content of the upper strata would be decreased and in the second case increased. These conclusions are indirectly verified by some interesting experiments of Professor King[1] in experimenting with the fluctuations of ground water in a large, cylindrical, galvanized iron tank. He found that the water in a circular well in the middle of the cylinder rose daily and fell again during the night. The application of cold water to the outside of the cylinder by means of a hose also caused the water in the well to fall. These results are fully consistent with the phenomena of surface tension. When the temperature of the soil was raised the surface tension of the water was lowered and more water was drawn into the lower part of the cylinder, which raised the level of the water in the well. When cold water was applied to the outer surface of the cylinder, the water in the soil was drawn up again through increased surface tension and the level of the water in the well was lowered.

The influence of temperature on the rate of flow of water in saturated soils is very great. This is due to a change in the viscosity of water with temperature, as has been pointed out in the section on viscosity. This property is not only of interest in considering saturated soils, but it is also an important factor in determining the rate of adjustment of water in soils in which saturation is not complete.

INFLUENCE OF TEXTURE AND STRUCTURE OF SOILS ON THE ACQUIREMENT AND RETENTION OF SOIL MOISTURE.

The limit of the capacity of any soil for water is reached when the surface tension holding the water in the capillary spaces is no longer able to overcome the force of gravity acting on the mass. The relative water capacity of two soils, therefore, depends principally upon the number and size of the capillary spaces. By a capillary space as used here is meant not any interstitial space in the soil structure, but only that portion of it which is near the point of contact of two soil grains. It is that portion in which the bounding walls are close together, separated only by distances of capillary magnitude and consequently most efficient in retaining water. It is evident that in a soil of fine texture

[1] U. S. Department of Agriculture Bul. No. 5, Weather Bureau, pp. 59-61.

the grains might be so close together as to make all the interstitial space capillary in its nature.

The one important factor which determines the acquirement and retention of soil moisture is the curvature of the capillary water surfaces. If equal volumes of two soils are placed in contact, and the curvature of the surface is less in the first than in the second, then water will move from the first to the second, increasing the curvature in one and decreasing it in the other until it becomes the same in both soils. If the second soil contains a greater number of capillary spaces than the first, it will contain more water when equilibrium is established. During the adjustment water will have actually moved from a soil containing a low percentage of water to one having a higher percentage. In no case, however, will water leave a capillary space having a water surface of large curvature to go to a space with a surface of less curvature. It is the form of the surface which determines the movement of the water.

In a form of structure presented by Dr. Soyka, to which reference has previously been made, and in which the spheres are arranged for the greatest amount of interstitial space, there are only about one-half as many points of contact between the grains as in another form of structure given, although the amount of interstitial space in the first case is twice as great. Consequently the second form—the compact soil—would have twice the water capacity of the first, since the number of capillary spaces formed is twice as great. The difference in this case would be due entirely to the structure of the soil, since the texture remains uniform.

In the same manner a soil of fine texture contains many more capillary spaces than a soil which is coarse, and consequently has a much greater water-holding power. In a coarse sandy soil the interstitial spaces are large, allowing percolation and drainage to take place rapidly, but permitting the formation of comparatively few capillary spaces for the storing of water. As the texture becomes finer the interstitial space becomes smaller and the capillary spaces increase in number, and embrace a large proportion of the whole interstitial space. The water capacity of the soil increases and percolation is greatly decreased. The limit is reached when the texture becomes so fine and the structure so close that all the interstitial space becomes capillary in its nature. The capacity of the soil for moisture in this case is reached only when all the interstitial space becomes filled with water, a condition found in some clay soils.

DISPLACEMENT OF CAPILLARY WATER THROUGH GRAVITATION.

In considering the adjustment of water among the capillary spaces and the arrangement of the film so as to present as little free space as possible, it was assumed that the action of gravity could be neglected. This is undoubtedly the case in the smaller capillary spaces, but in those existing between the larger soil grains gravitation causes a displacement of the capillary water, so that it is no longer symmetrically arranged about the point of contact. The action of gravity on the capillary water between two spheres is illustrated in fig. 7.

The model consists of rubber balls about 1 inch in diameter fastened together by small steel pins inserted normal to the surface at the points of contact. The whole is then immersed in cylinder oil and allowed to drain while in a vertical position. While the great size of the balls and the low surface tension of the liquid are conditions not found in soils, it nevertheless illustrates the principle involved. If the liquid had no weight it would be uniformly distributed about the line of centers of spheres. Gravitation, however, causes a distortion of the liquid from a position of symmetry about the point of contact. When the line of centers is horizontal, the liquid moves down until the pressure exerted by the upper portion of the film is equal to that exerted by the lower portion plus the weight of the liquid. The curvature of the upper part of the film must therefore be greater than that of the lower. The upper film is consequently drawn down into the capillary space until it acquires sufficient curvature to support the weight of the liquid and the tension of the opposing film. Reference to the figure will show the upper part of the film far down in the capillary space, while the lower part is well down on the surface of the spheres.

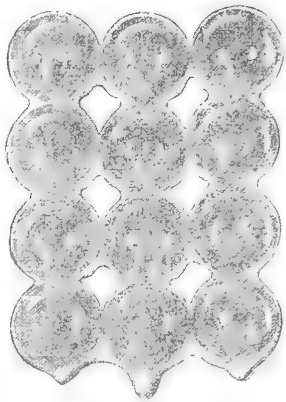

FIG. 7.—Displacement of capillary water through gravitation.

If the line of centers is vertical the curvature from the upper contact will gradually increase downward in order to compensate the effect of the weight of the liquid. This can be seen in the vertical films in the figure, and is well illustrated by the position assumed by a drop of ink between the opened blades of a ruling pen, held so that the blades lie in horizontal planes one above the other.

A consideration of the displacement of the water in the capillary spaces through the influence of gravity serves to give an idea of what takes place when the soil contains more water than the capillary spaces are able to retain. The upper part of the film is then unable to reach a position where it can balance the opposing forces, and water is moved through gravitation until the film is enabled to secure a position in which it can establish equilibrium. Such displacements of capillary water would occur only in the larger capillary spaces where a considerable mass of water would be subjected to the action of gravitation.

In considering the gravitation of water in soils, mention was made (p. 7) of the marked difference in water content of a vertical column of soil at different points along the column. Having developed the principles which regulate the movement of water in soils, the explanation of this non-uniform distribution of water in a vertical column can now be given.

Consider a single vertical column of soil grains as arranged in fig. 7, and suppose the capillary spaces to contain equal amounts of water. The amount of water in each capillary space is assumed to be less than the amount required to saturate it considered by itself, so that if the column were in a horizontal position the water would all be retained. Each capillary surface would in this case be supporting the water in the capillary space, together with the weight of the water in the connecting film on the surface of a soil grain. When the column is raised to a vertical position, the weight of the whole conducting film from top to bottom is thrown for an instant upon the capillary surface nearest the top. This capillary space immediately loses water until the pressure of the surface is equal to the pressure of the surface next below, plus a pressure sufficient to balance the weight of the water in the connecting film between the two surfaces. Both spaces then lose water together, maintaining this difference in pressure until the pressure of the second surface is equal to that of the third plus the pressure necessary to balance the weight of the connecting film, as before. The pressure of the first surface would now be equal to the pressure of the third, plus the pressure necessary to balance the weight of the two connecting films. The action would continue in this manner through each capillary surface until equilibrium is established.

The relative part taken by the different capillary surfaces in supporting the weight of the connecting column can be illustrated by means of the following mechanical analogue. Suppose a series of very thin elastic membranes stretched over circular hoops and supported horizontally one above the other, the distance between the membranes being very small. Now, let a heavy ball be placed upon the upper membrane. This membrane immediately stretches until it reaches the second, then the two stretch together until they touch the third, and so on, until the ball comes to rest. Suppose the membranes all had the same tension before the ball was put in place. After equilibrium is established the upper membrane will have the greatest tension, the second one the next greatest, and so on, analogous to the pressure of the capillary surfaces.

The pressure of the upper capillary surface will always exceed that of the lower surface by the pressure necessary to support the weight of the conducting column. This would necessitate the upper films having a much greater curvature, so that less water could be held in the capillary spaces. The water content should therefore increase uniformly from top to bottom. This has been shown to be the case with coarse sands.

In a soil of fine texture the number of capillary spaces is greatly increased. The pressure exerted by the capillary surfaces would therefore be much greater for the same water content. Consequently, the effect of the weight of the connecting films would be much lessened, and the water content of the soil would be much more uniformly distributed.

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BULLETIN No. 11. S. 13.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF SOILS.

TOBACCO SOILS OF THE UNITED STATES:

A PRELIMINARY REPORT UPON THE SOILS OF THE PRINCIPAL TOBACCO DISTRICTS.

BY

MILTON WHITNEY,
CHIEF OF DIVISION OF SOILS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1898.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Division of Soils,
Washington, D. C., November 1, 1897.

Sir: I have the honor to submit herewith and to recommend for publication a preliminary report upon the principal tobacco soils of the United States. It has not been possible, with the time and means at our disposal, to make an exhaustive study and map accurately the areas of the tobacco lands, but trips of reconnoissance have been taken over most of the important tobacco districts and a large amount of material has been examined. The results show a very marked difference in the texture and physical properties of the soils adapted to the different classes, types, and grades of tobacco, and give a basis for the classification of the soils and their mapping upon any desired scale. A recommendation has been made in my annual report that a more detailed study of these soils be undertaken and that reliable maps be prepared showing the area and distribution of the soils.

Respectfully,

Milton Whitney,
Chief of Division.

Hon. James Wilson,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

TOBACCO SOILS OF THE UNITED STATES: A PRELIMINARY REPORT UPON THE SOILS OF THE PRINCIPAL TOBACCO DISTRICTS.

INTRODUCTION.

In 1892, when the tobacco exhibit was being prepared for the Columbian Exposition, it was proposed to make a very comprehensive study of the soils of the principal tobacco areas of the country. This idea could not be carried out in full at the time, but a beginning was made and quite a large collection of typical tobacco soils secured. Since that time much attention has been given to the subject, a large number of samples have been collected by agents of the Department, and quite a large amount of this material has been examined in the laboratory. This publication is a preliminary report upon the work.

In recent years quite a little work has been done upon various lines connected with the production of tobacco, and a number of valuable publications have been issued. The most comprehensive and generally valuable paper was published in the volume of Agriculture of the Tenth Census. This article contains a great amount of exceedingly valuable information in regard to the soils and the influence of the soils on the tobacco crop of the United States.

Prof. O. Comes has published a valuable contribution on the botany of the tobacco plant in a short monograph, entitled Hortus Botanicus Porticensis, in which he attempts to classify botanically the tobaccos of the principal tobacco districts of the world. This was followed by the publication in 1897, by the same author, of the first volume of Del Tabacco—Storia, geografia, statistica, speciografia, agrologia e patologia.

Several valuable papers have been published in the annual reports of the Connecticut Experiment Station upon the progress of an investigation in tobacco culture at Poquonock for the past five years. Several bulletins have been issued from other experiment stations on this subject, notably the following: Bulletin No. 4 of the Colorado Experiment Station, published February, 1888, giving a description of the best tobacco soils, methods of cultivation, curing, and other treatment of the crop, together with the yield and quality of tobacco from a number of samples of seed sent out by the United States Department of Agriculture. Bulletin No. 20 (second series), of the Louisiana Experiment Station on Tobacco Growing in Louisiana, consists of an essay on the general subject of tobacco growing, together with experiments at the North Louisiana Experiment Station. This was followed the next year by the publication of Bulletin No. 25 (second series), containing the results of experiments made on the cultivation of tobacco in northern Louisiana. Bulletin No. 122, on Types of Tobacco and Their Analyses, published by the North Carolina Experiment Station in 1895, contains the results of the chemical analyses of a number of typical tobaccos from the principal tobacco areas of the country. In 1895 the Florida Experiment Station published a report on the Culture of Tobacco, followed in 1897 by a revised and somewhat enlarged edition. This was published as Bulletin No. 38, and called Tobacco in Florida. In 1896 the Kentucky Experiment Station published Bulletin No. 63 on Tobacco, containing the results of some fertilizer experiments on the yield of tobacco, together with a study of the effects of arsenites on the tobacco plant and its efficiency as an insecticide. Mention should also be made of a number of valuable papers on the cultivation of tobacco by our consular agents in the Consular Report, particularly those relating to the cultivation of tobacco in Sumatra and in Cuba. Another important contribution entitled Tobacco Leaf, by Killebrew and Myrick, published in 1897, covers the general subject of tobacco culture and curing.

STATISTICS OF TOBACCO CULTURE.

In order to study the question intelligently it was necessary carefully to consider the yield of the different States, the counties in each State and district which produced any considerable amount of tobacco, and be largely guided by this in collecting samples of soils for examination. The data for this work were taken mainly from the Tenth Census, on account of the detailed estimates and the very valuable descriptions given there of the tobacco areas, the soils, and the physical conditions in the areas. In order to judge how the conditions had changed in the ten years which had elapsed since the census was taken, the yield from the counties composing the principal districts was compared with the yield of the same counties given in the Eleventh Census, a preliminary bulletin of which, on Tobacco Production, was published shortly after these investigations were undertaken.

As there are no subsequent figures which admit of the detailed study that these census figures allow, they are given here to show the location of the different tobacco areas and incidentally to show the change in acreage and yield in the ten years elapsing between the Tenth and Eleventh Censuses.

TOBACCO PRODUCED IN FOUR CENSUS YEARS.

The table below furnishes a condensed and exact exhibit of the production of the tobacco regions of the United States and the changes that took place from 1859 to 1889.

States producing tobacco in 1889.	1859.	1869.	1879.	1889.
Over 1,000,000 pounds.	*Pounds.*	*Pounds.*	*Pounds.*	*Pounds.*
1. Kentucky	108, 126, 840	105, 305, 869	171, 120, 784	221, 880, 303
2. Virginia	121, 787, 946	37, 086, 364	79, 988, 868	48, 522, 655
3. Ohio	25, 092, 581	18, 741, 973	34, 735, 235	37, 853, 563
4. North Carolina	32, 853, 250	11, 150, 087	26, 986, 213	36, 375, 258
5. Tennessee	43, 448, 097	21, 465, 452	29, 365, 052	36, 368, 395
6. Pennsylvania	3, 181, 586	3, 467, 539	36, 943, 272	28, 956, 247
7. Wisconsin	87, 340	960, 813	10, 608, 423	19, 389, 166
8. Maryland	38, 410, 965	15, 785, 339	26, 082, 147	12, 356, 838
9. Missouri	25, 086, 196	12, 320, 483	12, 015, 657	9, 424, 823
10. New York	5, 764, 582	2, 349, 798	6, 481, 431	9, 316, 135
11. Connecticut	6, 000, 133	8, 328, 798	14, 044, 652	8, 874, 924
12. Indiana	7, 993, 378	9, 325, 392	8, 872, 842	7, 710, 297
13. Illinois	6, 885, 262	5, 249, 274	3, 935, 825	3, 042, 936
14. Massachusetts	3, 233, 198	7, 312, 885	5, 369, 436	2, 794, 848
15. West Virginia	2, 180, 366	2, 046, 452	2, 296, 146	2, 602, 021
Between 100,000 and 1,000,000 pounds.				
16. Arkansas	989, 980	594, 886	970, 220	954, 640
17. Florida	828, 815	157, 405	21, 182	470, 443
18. Georgia	919, 318	288, 596	228, 590	263, 752
19. South Carolina	104, 412	34, 805	45, 678	222, 898
20. Texas	97, 914	59, 706	221, 283	175, 706
21. Alabama	232, 914	152, 742	452, 426	162, 430
Less than 100,000 pounds.				
22. New Hampshire	18, 581	155, 334	170, 843	86, 593
23. Iowa	303, 168	71, 792	420, 477	74, 396
24. Vermont	12, 245	72, 671	131, 432	70, 518
25. Kansas	20, 349	33, 241	191, 669	62, 083
26. Mississippi	159, 141	61, 012	414, 663	61, 511
27. Louisiana	39, 940	15, 541	55, 954	46, 845
28. New Jersey	149, 485	40, 871	172, 315	33, 855
29. Delaware	9, 699	250	1, 278	29, 680
30. Minnesota	38, 938	8, 247	69, 922	23, 285
31. California	3, 150	63, 809	73, 317	12, 907
32. Michigan	121, 099	5, 385	83, 969	11, 984
33. Nebraska	3, 636	5, 988	57, 979	11, 049
34. Washington	10	1, 682	6, 930	7, 040
35. Oregon	405	3, 847	17, 325	3, 325
36. New Mexico	7, 044	8, 587	890	1, 415
Total	434, 291, 913	262, 732, 755	471, 655, 305	482, 244, 764

This table gives the yield of States according to the production in 1889, the first group comprising those States in which the production exceeded 1,000,000 pounds, the second group comprising those States in which the production is between 100,000 and 1,000,000 pounds, the third group embracing the States producing less than 100,000 pounds.

ESTIMATES OF TOBACCO PRODUCTION IN 1896.

The following are the final estimates of the Division of Statistics of this Department for the year 1896:

Area, yield, and value of tobacco in 1896.

State.	Area cultivated.	Yield.	Value.
	Acres.	*Pounds.*	
Kentucky	196,745	143,623,850	$6,032,202
North Carolina	134,567	68,629,170	5,490,334
Virginia	92,002	57,961,260	3,013,986
Tennessee	53,351	35,211,660	2,464,816
Ohio	32,012	23,688,880	1,066,000
Maryland	15,995	9,277,100	398,915
Pennsylvania	13,884	16,244,280	1,299,542
Indiana	11,957	8,130,760	365,884
Missouri	10,580	7,406,000	666,540
Connecticut	6,579	10,197,450	1,325,668
West Virginia	5,119	3,685,680	313,283
Wisconsin	3,975	5,088,000	279,840
Illinois	3,902	2,497,280	237,242
New York	3,259	3,389,360	271,149
Arkansas	2,950	1,327,500	146,025
Alabama	2,147	1,009,090	161,454
Massachusetts	1,975	3,199,500	383,940
Other States	3,750	2,437,500	341,250
Total	594,749	403,004,320	24,258,070

PRINCIPAL TOBACCO DISTRICTS.

The Department is constantly in receipt of letters asking for information and advice in regard to the growing of tobacco. The main points of inquiry seem to be in regard to the kind of tobacco which should be grown and the method of curing the product.

Climate and soil conditions should determine the kind of tobacco raised. The tobacco plant readily adapts itself to a great range of climatic conditions, will grow on nearly all kinds of soil, and has a comparatively short season of growth. It can, therefore, as a matter of fact, be grown in nearly all parts of the country, even where wheat and corn can not be economically produced. But while tobacco can be so universally grown, the flavor and quality of the leaf are greatly influenced by the conditions of climate and soil. The industry has been very highly specialized and there is only demand now for tobacco possessing certain qualities, adapted to certain specific purposes. A nondescript tobacco is not worth growing and should not be grown, as it lowers the price of really good types of tobacco, to the detriment alike of the grower and the consumer. It is important, therefore, to understand what kinds of tobacco are in demand and what the climatic and soil conditions are which will most easily produce the qualities desired.

The principal kinds of tobacco grown in this country are the cigar types, for our domestic supply of cigars; the manufacturing types, for smoking and chewing, for our domestic use; the bright yellow tobacco, for cigarettes, smoking, and plug wrappers; White Burley, for smoking and chewing, both for domestic and export trade; and the export types proper, which are not suited to our domestic use, but which are mainly exported to foreign countries to be used both for cigar and manufacturing purposes. The question is often asked, Which of these classes of tobacco should be grown?

CHANGES IN PRODUCTION OF TOBACCO FROM 1879 TO 1889.

The following table, compiled from the Eleventh Census, shows where these different classes of tobacco are produced, the acreage of the different tobacco districts in 1879 and 1889, together with the increase or decrease in acreage and yield in 1889 as compared with the acreage and yield of 1879. The plus sign in the table indicates an increase; the minus sign indicates a decrease.

Comparison of acreage and yield for 1879 and 1889, by districts.

Districts.	Relation of acreage in each district to total acreage in 1889.	Acreage.		Change in each district.		Change in whole area.	
		1879.	1889.	Acres.	Yield.	Acres.	Yield.
Cigar leaf:	*Per cent.*	*Acres.*	*Acres.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Seed leaf, Ill	0.3	752	329	— 56.2	— 62.7	— 0.58	— 0.68
Massachusetts	2.2	3,358	2,012	— 40.1	— 92.1	— 1.84	— 2.67
Connecticut	6.9	8,666	6,331	— 26.9	— 36.8	— 3.20	— 4.93
Indiana	9.2	9,859	8,378	— 15.0	— 7.0	— 2.03	— .53
Pennsylvania	29.2	26,347	26,746	+ 1.5	— 19.4	+ .54	— 7.24
Seed leaf, Ohio	23.2	15,017	21,224	+ 41.2	+ 5.9	+ 8.52	+ 1.04
New York	9.1	4,264	8,289	+ 94.3	+ 56.1	+ 5.52	+ 3.33
Wisconsin	18.6	8,509	17,000	+ 99.8	+ 83.3	+11.66	+ 9.05
Florida	.04	35	1,100	+3042.8	+3570.5	+ 1.32	+ .44
Total	98.74	76,807	91,409			+21.91	— 2.19
Manufacturing and export:							
Red and spangled, W. Va	.05	568	187	— 68.0	— 72.3	— .10	— .11
Manufacturing, Mo	.4	2,977	1,205	— 59.5	— 59.4	— .50	— .42
Sun and air cured fillers, Va	.8	6,285	2,616	— 58.3	— 69.9	— 1.05	— 1.29
Maryland	5.4	37,741	17,778	— 52.9	— 52.6	— 5.72	— 5.73
Spangled, Ohio	1.1	7,581	3,604	— 52.4	— 51.6	— 1.14	— 1.41
Green River, Ky	.9	6,419	3,123	— 51.3	— 51.3	— .91	— .91
Red shipping, Va	1.1	6,516	3,721	— 42.8	— 54.1	— .80	— .91
Heavy tobacco, Mo	2.0	10,018	6,862	— 31.5	— 26.2	— .90	— .98
Cumberland River, Ky	.8	3,844	2,729	— 29.0	— 27.5	— .31	— .28
Upper Green River, Ky	4.3	17,676	14,440	— 17.9	— 12.9	— .92	— .65
Ohio River, Ky	4.2	18,297	14,203	— 2.2	— 26.4	— 1.17	— 1.47
Upper Cumberland River, Tenn	1.6	5,421	5,398	— .4	— 14.2	+ .01	— .27
Paducah, Ky	8.4	28,205	28,188	— .1	— 14.0	.00	— 1.26
Lower Green River, Ky	14.9	50,313	50,088	.0	+ 1.2	.00	+ .21
Clarksville, Ky	13.7	45,756	45,753	.0	+ 4.1	.00	+ .55
Export, Ill	.9	2,999	3,029	+ 1.0	+ 9.2	+ .01	+ .07
Benton County, Ark	.3	844	940	+ 11.4	+ 1.1	+ .02	.00
West Tennessee, Tenn	3.7	10,103	12,432	+ 23.0	+ 13.2	+ .66	+ .41
Clarksville, Tenn	8.8	22,912	29,652	+ 29.4	+ 37.3	+ 1.93	+ 2.53
Dark shipping, W. Va	.5	1,342	1,819	+ 35.5	+ 30.7	+ .13	+ .18
North Carolina	*a* 22.3	*a* 48,005	*a* 74,848	+ 55.9	+ 24.4	+ 7.69	+ 2.34
Total		348,665	334,941			—13.87	—10.34
Bright yellow:							
Virginia	*b* 40.2	*b* 52,565	*b* 51,281	— 2.4	— 24.1	— 1.26	—13.31
West Virginia	1.1	1,169	1,390	+ 10.3	+ 17.0	+ .21	+ .20
North Carolina	58.8	*b* 48,005	*b* 74,848	+ 55.9	+ 24.4	+30.31	+10.98
Total		101,739	127,519			+29.26	— 2.13
White burley:							
Ohio	15.3	11,258	17,250	+ 53.2	+ 37.4	+ 9.25	+ 7.02
Kentucky	84.7	53,475	95,563	+ 78.7	+ 86.3	+65.01	+69.97
Total		64,733	112,813			+74.26	+76.99

a There is no way of estimating separately the acreage in yellow and in manufacturing in this State. It is generally believed the acreage in manufacturing is greatly decreased and that in yellow has increased. This estimate is but approximate.

b Including also flue-cured fillers.

A glance at the table shows that in this period of ten years the acreage and yield of the cigar tobaccos have been very considerably increased. The manufacturing and export districts can not be sharply separated, as both kinds of tobacco are frequently grown in the same district and the same kind is frequently used for both purposes. It will be seen that on the whole there has been a considerable decrease in the acreage and yield. With the bright yellow and burley tobaccos there has been a large increase in both acreage and yield. This table gives an idea where the different kinds of tobacco are raised in such quantities and of such commercial importance as to constitute a district. Since 1889 there has been considerable change in many of these districts, while other new districts, notably Texas and California, are coming into considerable prominence both as to the area under cultivation and the excellent quality of the product raised. The acreage in Florida has also been very greatly increased since 1889, but there are no reliable statistics to show the extent of the changes in the counties making up the tobacco districts.

COUNTIES CONSTITUTING THE TOBACCO DISTRICTS OF THE UNITED STATES.

The following are the counties in each State making up the different tobacco districts of the country. This gives only a very approximate idea of the area of the districts, as the boundaries follow geological and soil formations rather than county lines, and consequently only small portions of some of the counties are included in the districts. The counties are given in the order of their acreage in 1889, those having the largest acreage being given first. The numerals immediately after the names of the States show the percentage of the total tobacco acreage of the State in 1889 included in the counties named. Only those counties producing notable quantities of tobacco are here mentioned.

District of cigar types.

States and varieties.	Product of State.	Counties.
Illinois:	*Per cent.*	
Seed leaf	7.9	Jo Daviess, Stephenson, Carroll.
Massachusetts	100	Hampshire, Hampden, Franklin, Berkshire.
Connecticut	100	Hartford, Litchfield, Fairfield, Tolland, Middlesex, New Haven.
Indiana	89.4	Switzerland, Spencer, Warrick, Jefferson, Dubois, Ohio, Pike.
Pennsylvania	99.2	Lancaster, York, Chester, Bradford, Clinton, Tioga, Bucks, Lebanon, Northumberland, Lycoming, Dauphin, Cumberland.
Ohio:		
Seed leaf	47.8	Montgomery, Darke, Preble, Warren, Miami, Butler, Clinton, Clark, Shelby, Champaign, Greene.
New York	96	Onondaga, Cayuga, Chemung, Oswego, Steuben, Wayne, Tompkins, Tioga.
Wisconsin	98.6	Dane, Rock, Jefferson, Columbia, Vernon, Green.
Florida	92.4	Gadsden, Walton, Madison, Columbia, Leon.

District of manufacturing and export types.

States and varieties.	Product of State.	Counties.
West Virginia:	*Per cent.*	
Red spangled	4	Lewis, Wirt, Calhoun, Ritchie, Roane, Wetzel.
Dark shipping	38.9	Putnam, Cabell, Wayne, Kanawha, Jackson, Mason, Wood.
Missouri:		
Manufacturing	10.6	Callaway, Montgomery, Pike, Lincoln, Warren, Osage, Franklin.
Heavy	60.5	Chariton, Howard, Carroll, Saline, Macon, Linn, Randolph, Livingston, Monroe, Boone, Shelby.
Virginia:		
Sun and air cured	2.4	Louisa, Caroline, Hanover, Spottsylvania.
Red shipping	3.4	Dinwiddie, Fluvanna, Goochland, Rockbridge, Chesterfield.
Flue-cured fillers	11.1	H-nry, Franklin, Patrick. (See also Bright yellow.)
Maryland	99	Prince George, St. Mary, Anne Arundel, Charles, Calvert, Montgomery, Harford, Frederick.
Kentucky:		
Green River	1.1	Ohio, Butler.
Cumberland River	1	Metcalfe, Adair, Cumberland, Monroe, Pulaski, Russell, Casey, Wayne, Clinton.
Upper Green River	5.2	Hart, Barren, Warren, Green, Marion, Allen, Taylor, Grayson, Larue, Hardin, Edmonson.
Ohio River	5.1	Caldwell, Breckinridge, Crittenden, Lyon, Hancock, Livingston, Meade.
Paducah	10.2	Graves, Calloway, Ballard, McCracken, Marshall, Fulton, Hickman.
Lower Green River	18.2	Henderson, Daviess, Webster, Hopkins, Union, McLean, Muhlenberg.
Clarksville	16.6	Christian, Logan, Todd, Trigg, Simpson.
Ohio:		
Spangled	8.1	Washington, Noble, Monroe, Belmont, Morgan, Guernsey, Gallia, Athens, Harrison.
Tennessee:		
Upper Cumberland River.	10.5	Sumner, Smith, Macon, Trousdale, Jackson, Wilson, Putnam, Clay.
Clarksville	57.6	Montgomery, Robertson, Cheatham, Stewart, Dickson, Houston, Humphreys.
West Tennessee	24.1	Weakley, Henry, Obion, Benton, Dyer, Carroll, Gibson, Henderson, Hardeman, Decatur.
Illinois:		
Export	72.9	Saline, Williamson, Franklin, Hamilton.
Arkansas	50.1	Benton, Washington, Boone, Madison, Carroll, Newton, Izard, Randolph.
North Carolina	77.1	Rockingham, Granville, Stokes, Caswell, Person, Madison, Vance, Forsyth, Buncombe, Surry, Durham, Guilford, Alamance. (Including also Bright yellow.)

District of bright yellow type.

State.	Product of State.	Counties.
	Per cent.	
Virginia	46.3	Pittsylvania, Halifax, Henry, Franklin, Patrick.
West Virginia	29.9	Fayette, Mercer, Summers, Monroe, Raleigh.
North Carolina	....	(See counties under export tobacco.)

District of whit burley type.

State.	Product of State.	Counties.
	Per cent.	
Ohio	38.9	Brown, Clermont, Adams.
Kentucky	34.8	Mason, Owen, Bracken, Henry, Bourbon, Scott, Pendleton, Grant, Fleming, Harrison, Shelby, Boone, Nicholas, Carroll, Woodford, Montgomery, Franklin, Kenton, Lewis, Trimble, Robertson, Campbell, Gallatin, Oldham.

INFLUENCE OF CLIMATE ON THE DISTRIBUTION OF THE DIFFERENT CLASSES OF TOBACCO.

It is a curious and interesting fact that tobacco suitable for our domestic cigars is raised in the latitude of Sumatra, Cuba, and Florida, and then passing over our middle tobacco States, the cigar type is found again in Massachusetts, Connecticut, Pennsylvania, Ohio, Indiana, Illinois, and Wisconsin. The tobacco which we use only for chewing and smoking and which we send abroad is raised in the intervening States, the very best locality lying just below the latitude of southern Ohio. This is undoubtedly a matter of climate, although the ordinary meteorological statistics do not show any good reason for the facts. (See Plates I and II.)

METEOROLOGICAL CONDITIONS IN THE GREAT TOBACCO REGIONS.

The following table gives a summary of the meteorological conditions in a number of the tobacco districts of our own country, and from an eight years' record in Habana and from several years' record in the Island of Sumatra and the adjacent coast:

Mean monthly temperatures.

District.	Apr.	May.	June.	July.	Aug.	Sept.
	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Connecticut Valley	44.80	56.50	65.90	70.20	67.70	61.11
Pennsylvania	49.90	62.00	71.80	75.90	73.30	65.63
Kentucky	57.50	65.00	75.30	77.20	75.30	69.63
Tennessee	60.60	68.10	77.00	79.50	77.93	70.53
Virginia	56.00	65.80	74.00	77.80	75.40	69.00
North Carolina	58.20	67.00	75.80	78.70	76.00	70.10
Sumatra	83.05	82.90	82.35	82.45	81.35	81.45

District.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Habana	78.60	75.40	72.50	72.00	73.60	75.20

Mean maximum temperatures.

District.	Apr.	May.	June.	July.	Aug.	Sept.
	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*	°*F.*
Connecticut Valley	56.70	69.00	78.00	82.10	78.90	71.23
Pennsylvania	60.90	71.20	81.60	84.50	82.80	74.98
Kentucky	70.40	79.80	84.80	84.50	81.30	78.90
Tennessee	70.50	78.80	86.10	89.60	87.20	80.75
Virginia	66.60	76.20	83.60	87.20	84.20	78.20
North Carolina	69.80	78.30	86.10	87.00	84.00	78.30
Sumatra	89.35	88.80	87.50	87.80	86.90	87.15

District.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Habana	82.40	79.90	77.00	77.40	79.00	80.80

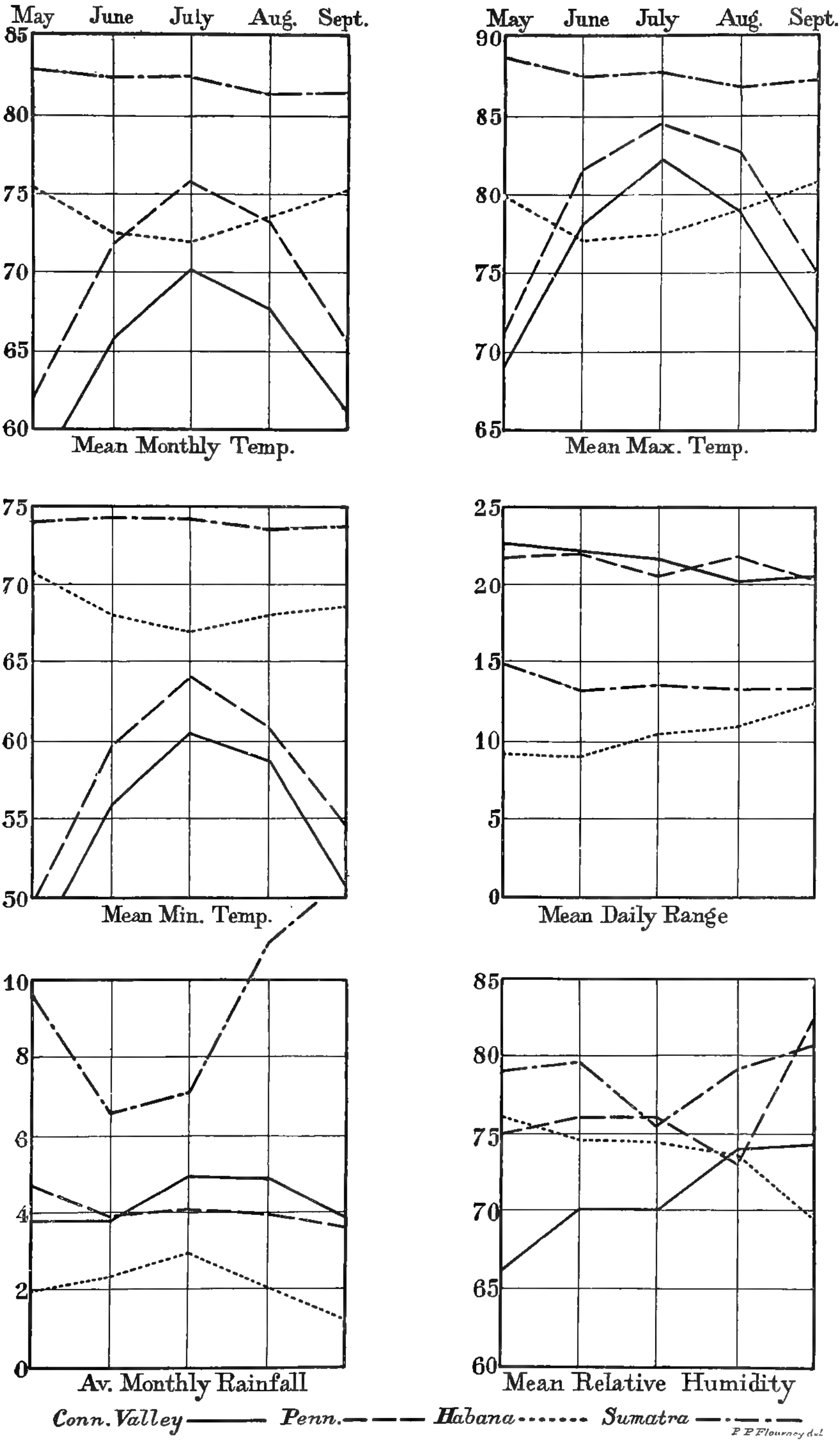
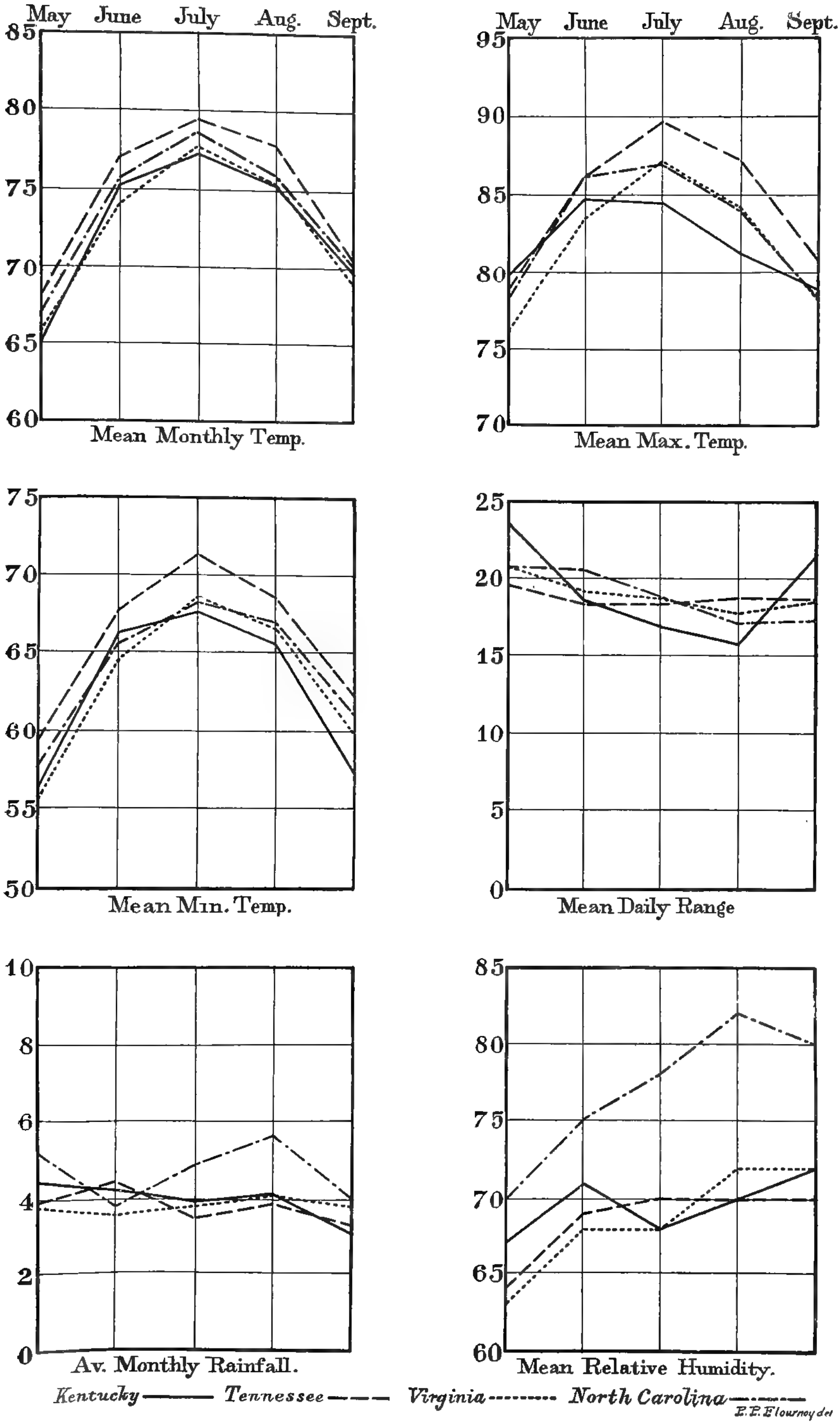

May June July Aug. Sept.
85 80 75 70 65 60
Mean Monthly Temp.
May June July Aug. Sept.
90 85 80 75 70 65
Mean Max. Temp.
75 70 65 60 55 50
Mean Min. Temp.
25 20 15 10 5 0
Mean Daily Range
10 8 6 4 2 0
Av. Monthly Rainfall
85 80 75 70 65 60
Mean Relative Humidity
Conn. Valley
Penn.
Habana
Sumatra
F. P. Flournoy del.

PLATE II.


May
June
July
Aug.
Sept.
Mean Monthly Temp.
Mean Max. Temp.
Mean Min. Temp.
Mean Daily Range
Av. Monthly Rainfall.
Mean Relative Humidity.
Kentucky
Tennessee
Virginia
North Carolina

Mean minimum temperatures.

District.	Apr.	May.	June.	July.	Aug.	Sept.
	°F.	°F.	°F.	°F.	°F.	°F.
Connecticut Valley	35.40	46.50	55.90	60.50	58.80	50.87
Pennsylvania	39.50	49.40	59.70	64.00	61.00	54.68
Kentucky	47.90	56.20	66.20	67.60	65.60	57.35
Tennessee	51.50	59.30	67.80	71.30	68.50	62.25
Virginia	45.40	55.50	64.50	68.50	66.50	59.90
North Carolina	47.90	57.60	65.60	68.20	66.90	61.10
Sumatra	74.40	74.00	74.25	74.15	73.60	73.70

District.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Habana	74.10	70.70	68.00	66.90	68.00	68.40

Mean daily ranges of temperature.

District.	Apr.	May.	June.	July.	Aug.	Sept.
	°F.	°F.	°F.	°F.	°F.	°F.
Connecticut Valley	21.3	22.5	22.1	21.6	20.1	20.4
Pennsylvania	21.4	21.8	21.9	20.5	21.8	20.3
Kentucky	22.5	23.6	18.6	16.9	15.7	21.6
Tennessee	19.0	19.5	18.3	18.3	18.7	18.5
Virginia	21.2	20.7	19.1	18.7	17.7	18.3
North Carolina	21.9	20.7	20.5	18.8	17.1	17.2
Sumatra	14.9	14.8	13.2	13.6	13.3	13.4

District.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Habana	8.3	9.2	9.0	10.5	11.0	12.4

Records of rainfall.

District.	Averages for months.						Totals.	
	Apr.	May.	June.	July.	Aug.	Sept.	6 months.	Year.
	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.	Inches.
Connecticut Valley	3.33	3.78	3.79	4.90	4.86	3.85	24.24	49.23
Pennsylvania	3.61	4.70	3.91	4.06	3.96	3.68	23.92	43.74
Kentucky	4.98	4.46	4.25	3.97	4.12	3.06	24.86	51.70
Tennessee	5.21	3.92	4.44	3.45	3.89	3.28	24.19	52.10
Virginia	3.30	3.80	3.60	3.80	4.10	3.80	22.40	44.50
North Carolina	3.21	5.21	3.80	4.89	5.64	4.00	26.75	45.25
Sumatra	5.93	9.61	6.59	7.07	10.99	12.71	52.90	....

District.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	6 months.	Year.
Habana	6.57	1.94	2.27	2.95	2.06	1.21	17.00	49.83

Mean relative humidity.

District.	Apr.	May.	June.	July.	Aug.	Sept.
	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.	Per ct.
Connecticut Valley	63.00	66.00	70.00	70.00	74.00	74.33
Pennsylvania	70.00	75.00	76.00	76.00	73.00	82.33
Kentucky	64.00	67.00	71.00	68.00	70.00	72.00
Tennessee	61.00	64.00	69.00	70.00	70.00	70.00
Virginia	59.00	63.00	68.00	68.00	72.00	72.00
North Carolina	67.00	70.00	75.00	78.00	82.00	80.00
Sumatra	76.50	79.00	79.50	75.50	79.00	80.50

District.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
Habana	76.90	76.10	74.60	74.40	73.60	69.30

Average number of rainy days.

District.	Apr.	May.	June.	July.	Aug.	Sept.
Connecticut Valley	8	11	9	10	9	8
Pennsylvania	10	13	10	9	9	8
Kentucky	10	12	12	8	8	7
Tennessee	11	11	11	10	8	7
Virginia	11	12	12	11	12	9
North Carolina	9	13	11	14	13	10
Sumatra	13	14	12	11	14	15
District.	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**	**Mar.**
Habana	15	10	9	8	6	6

The Sumatra tobacco imported into this country is used only for a wrapper for our domestic cigars; it is not suitable for fillers nor for any other purpose in the market. The Habana tobacco is suitable both for cigar wrapper and filler. The Connecticut tobacco which is grown at present is valued mainly as a wrapper and binder leaf; the Pennsylvania tobacco is used mainly as a filler, the cigars being wrapped with a leaf from other localities. The same is true of the Ohio tobacco. The principal tobacco season in Cuba is about the opposite of our own. Several crops of tobacco can be grown there each season, but the main planting season is in November and December, while with us it is in May and June. It is surprising to find so little difference in the mean meteorological records for these several places during the crop season. There does not seem to be sufficient difference to explain the distribution of the different classes of tobacco, and yet this distribution is probably due mainly to climatic conditions.

EXPERIENCE THE ONLY SAFE TEST OF CLIMATE FOR TOBACCO.

One must still judge, so far as the climate is concerned, mainly from the experience of others as to the class of tobacco to be raised, as the ordinary meteorological record will be of very little value in determining this point. The plant is far more sensitive to these meteorological conditions than are our instruments. Even in such a famous tobacco region as Cuba tobacco of good quality can not be grown in the immediate vicinity of the ocean or in certain parts of the island, even on what would otherwise be considered good tobacco lands. This has been the experience also in Sumatra and in our own country, but the influences are too subtle to be detected by our meteorological instruments.

Little, therefore, can be said at the present time in regard to the suitable climatic condition for tobacco of any particular type or quality.

SOILS OF THE TOBACCO DISTRICTS.

Under given climatic conditions the class and type of tobacco depend upon the character of the soil, especially on the physical character of the soil upon which it is grown, while the grade is dependent largely upon the cultivation and curing of the crop. The different types of tobacco are grown on a wide range of soils all the way from the coarse, sandy lands of the pine barrens to the heavy clay, limestone, grass, and wheat lands. The best soil for one kind of tobacco, therefore, will be almost worthless for the staple agricultural crops, while the best for another type of tobacco will be the richest and most productive soil of any that we have. It is particularly true of tobacco, to a greater extent, perhaps, than of any other crop, that the texture and physical properties of the soil influence the physiology of the plant to such an extent as to determine and control the distribution of the different widely distinct types of tobacco. Soils producing a heavy shipping tobacco will not produce fine tobacco of any variety. Soils containing a large proportion of clay, or which for other reasons are very retentive of moisture, tend to produce large, heavy plants which cure to a dark brown or red. A lighter, sandy soil produces a plant having a thinner and more delicate leaf, which by proper treatment can be cured to a bright red, mahogany, or fine yellow color. So marked is this influence of soil upon the quality of the tobacco that a fine, bright tobacco land may be separated by only a few feet from a heavier clay soil which will produce only a heavy manufacturing or export leaf.

Manures and fertilizers tend always to increase the yield per acre, but where large quantities of nitrogen are added to the soil there is a tendency for the leaf to become thicker, heavier, and more gummy. In the case of the fine, bright tobaccos or naturally thin-textured leaves this is apt to cause a marked deterioration in the character of the leaf; but with the heavier varieties this result is far from undesirable, because it merely increases the normal influences of the soil in making the leaf heavier, richer, and of more body. Considerable control can therefore be exercised upon the quality or grade of the leaf, not only by judicious cultivation, but by proper fertilization.

A person well acquainted with the practical work of growing tobacco can readily tell from a simple inspection of the soil what special kind of tobacco the soil will grow and in what condition the soil is for tobacco cultivation. There is some physical, tangible evidence that indicates to the experienced eye whether the conditions are favorable for tobacco growing, whether the land would produce a given type, or whether a nondescript tobacco would be produced. The evidence upon which this judgment is based appears to be the texture or coarseness of the soil grains and the water content. The present investigation is based upon this.

THE TEXTURE OF TOBACCO SOIL.

The texture of a soil can be determined very satisfactorily by the method of mechanical analysis which has been described in Bulletin No. 4 of this division. The method consists of separating the particles of soil into grades of different sizes, which are especially distinguished as sand, silt, and clay, and weighing the quantity of each grade. The texture of a soil controls to a large extent its relation to water and the relative amount of water that it will contain. As a rule, the more clay a soil contains the more water it will hold; for the spaces in the clay soil are so exceedingly small that the water moves very slowly and a relatively large proportion of the rainfall is retained for the use of plants. The texture of the soil, however, does not altogether determine the relative amount of water which the soil will contain, for the arrangement of the soil grains also has a very important influence upon the water content. If the grains are evenly distributed, as in a puddled soil, the soil is much more retentive of moisture than where they are gathered together in flocks or segregated into masses, as in a loamy soil; for when the spaces in the soil between the grains are of nearly uniform size, as they are in a puddled soil, the movement of the water is very much slower than where the spaces are of various sizes, as in a loamy soil. Therefore, while the texture of a soil is a very important factor in the classification of the tobacco lands, the structure, or the arrangement of the soil grains, is also an important factor which must be considered at the same time. The arrangement of the soil grains is not an easy matter to determine, and there is no satisfactory way of expressing the difference in the structure of two soils. It is therefore necessary to determine the texture and to rely upon actual moisture determinations in the soil to determine the structure and the actual relation of the soil to water.

A great many samples of soil and subsoil have been collected from most of the important tobacco districts, and enough of these have been analyzed to enable generalizations to be made as to the character of the soils. Continuous records have been kept for several years of the moisture content of the soils in one or two localities only, in some of the principal tobacco districts. This work should be extended and continuous records kept of the soil condition in a number of places in each district.

SOILS OF THE NORTHERN CIGAR TOBACCO DISTRICTS.

The grade of tobacco used to wrap a cigar for domestic purposes is quite different from that suitable for the filler. Theoretically the wrapper leaves are the best on the plant, the binders are second quality, while all the other leaves are used for filler purposes. The one plant, therefore, is supposed to produce the filler, binder, and wrapper for the complete cigar. As a matter of fact, this is seldom satisfactorily accomplished with the same plant except in Cuba and our Southern States. In the Northern tobacco States a plant which will produce a good wrapper leaf does not, as a rule, make a very good filler. Good domestic wrapper leaf is worth anywhere from four to twenty times as much per pound as a filler leaf, but as the filler leaf is grown on heavier soil, with closer planting, the yield per acre is much larger and, as the cultivation and treatment of the tobacco is less expensive, the return per acre, even at the low price per pound at which it is sold, can be made as profitable as the wrapper.

The Pennsylvania filler is seldom wrapped now with its own leaf. It is wrapped with either a Cuban, Sumatra, Connecticut Valley, or Wisconsin wrapper. A Connecticut wrapper seldom wraps its own leaves, but is used on a Cuban, Pennsylvania, Ohio, or Wisconsin filler. The present prevailing grade in the Connecticut Valley is a wrapper leaf, the second quality being used as binder. In Pennsylvania at the present time the quality is a filler leaf, except on the river lands, where a light, thin-textured leaf is produced, which makes wrappers of a superior quality. The New York lands produce a good type of wrapper, and the crop at present is mainly a wrapper and binder grade. The Ohio tobacco is essentially a filler, and is covered with a Cuban, Sumatra, Connecticut Valley, or Wisconsin wrapper. The tobacco lands of Wisconsin appear to be nearly an average of the other States, and to produce in nearly equal excellence a wrapper and a filler leaf. It is commonly called a binder State.

THE CONNECTICUT VALLEY SOILS.

The tobacco soils of the Connecticut Valley are confined at present to the light, alluvial, sandy terraces and plains bordering the Connecticut River from northern Massachusetts down to within a few miles of the Sound. (See Plates III and IV.) These soils are the general type of the early truck soils of the Atlantic Coast. As a rule the lighter the texture—that is, the less clay they contain—the thinner the texture of the tobacco leaf and the more elastic, pliable and better the wrapper it will make. The yield per acre, however, on these very light soils is very small, and the care necessary to keep the plant growing and to protect it from the occasional drought is expensive; so that there is a limit of profitable production. On these light soils the plant must be kept growing at all hazards, for if the growth is retarded by too great a deficiency of water at any time, the plant will be small and the leaves thick and harsh. With continuous and rapid growth, such as is secured on these soils in favorable seasons, the leaf is of very thin texture, silky, pliable, light-colored, and admirably adapted for a cigar wrapper. Unquestionably some form of irrigation could be profitably adopted on these soils. It is the experience in Florida that if the plant can be kept growing by frequent rains or by judicious irrigation, the maturity of the crop can be greatly hastened; so that the growing season is only about half as long as it would be under unfavorable weather conditions. Every possible means should be taken to secure a continuous growth, and any check, however slight it may seem, must be regarded as a positive injury to the quality of the product if it is to be used as a wrapper leaf. The wrapper should have little body and but little flavor.

The binder is a low-grade wrapper which, from its quality or appearance or both, is not suitable for the outside covering of the cigar.

The filler leaf, being worth much less per pound than the wrapper, is too often neglected in this country, and when cured is but little better than dried leaves or has a very rank, strong flavor. This is a very great mistake, as the filler, forming the main bulk of the cigar, should give it character and flavor. Too much care and attention could not be given to the growing and fermenting of the filler leaf, were it not for the fact that the market demands a good-looking cigar above all else. The quality is a very much smaller factor in determining the market value. The filler should always be a leaf of good body and much stronger and richer in its flavor than the present type of wrapper. The rich, heavy clay soils of Pennsylvania and Ohio are admirably adapted to produce a rich, heavy filler leaf. Unfortunately, the methods of curing and fermentation are not so controlled as to develop the best quality of the leaf, as is done in Cuba.

The accompanying table gives the average results of the mechanical analyses, showing the texture of a number of subsoils of the Northern cigar tobacco lands:

Mechanical analyses of subsoils.

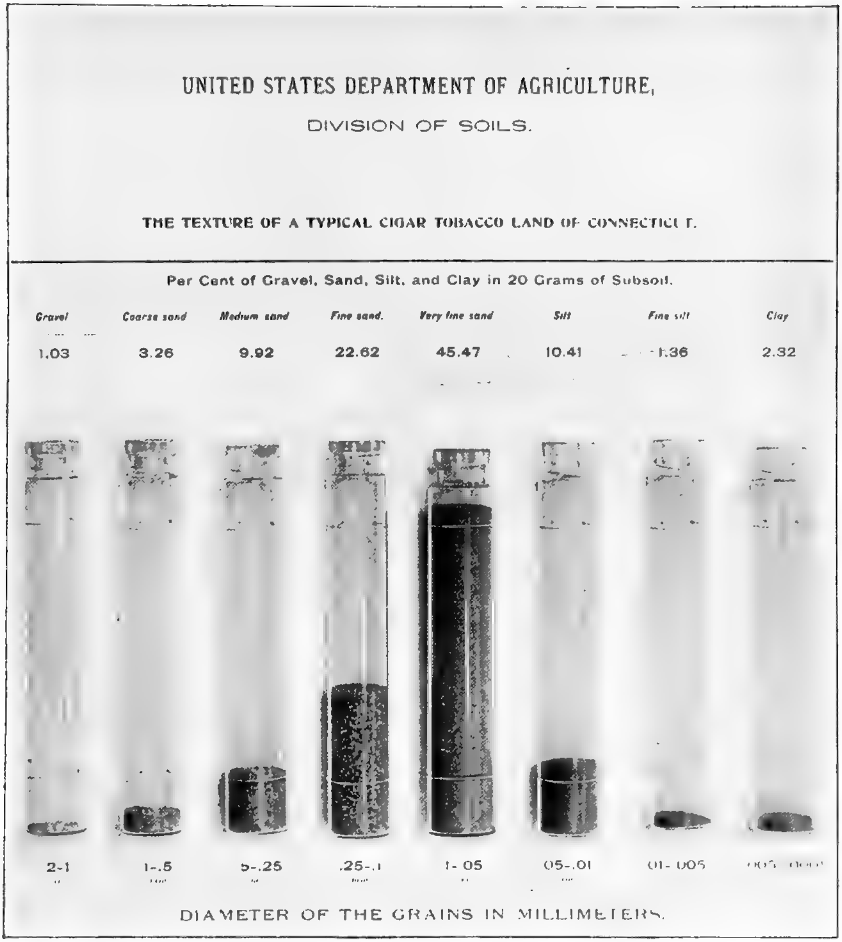
No. of samples.	District.	Principal grade of leaf produced at the present time.	Moisture in air-dry sample.	Organic matter.	Gravel (2-1 mm.).	Coarse sand (1-0.5 mm.).	Medium sand (0.5-0.25.).	Fine sand (0.25-0.1 mm.).	Very fine sand (0.1-0.05 mm.).	Silt (0.05-0.01 mm.).	Fine silt (0.01-0.005 mm.).	Clay (0.005-0.0001 mm.).
			P. ct.	*P. ct.*	*P. ct*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
9	Connecticut ...	Wrapper and binder.	0.76	2.53	1.03	3.26	9.92	22.62	45.47	10.41	1.36	2.32
5	Massachusetts.	.....do	.61	2.20	.00	.04	.71	10.09	49.26	30.89	2.71	3.31
10	New York.....	.....do	1.06	2.82	1.94	2.80	9.02	24.47	32.52	15.09	3.09	7.43
5	Pennsylvania *a*	.....do	2.03	3.23	.67	1.23	5.87	6.62	37.18	23.41	5.21	13.80
10	Wisconsin.....	Binder.........	4.70	2.93	.59	1.09	4.98	10.34	15.68	31.04	6.01	22.76
4	Ohio...........	Filler..........	3.05	2.67	.39	.76	2.25	5.04	15.36	37.60	6.41	27.52
6	Pennsylvania *b*	.....do	3.61	4.47	.68	.78	.91	2.47	13.89	34.23	9.79	29.27

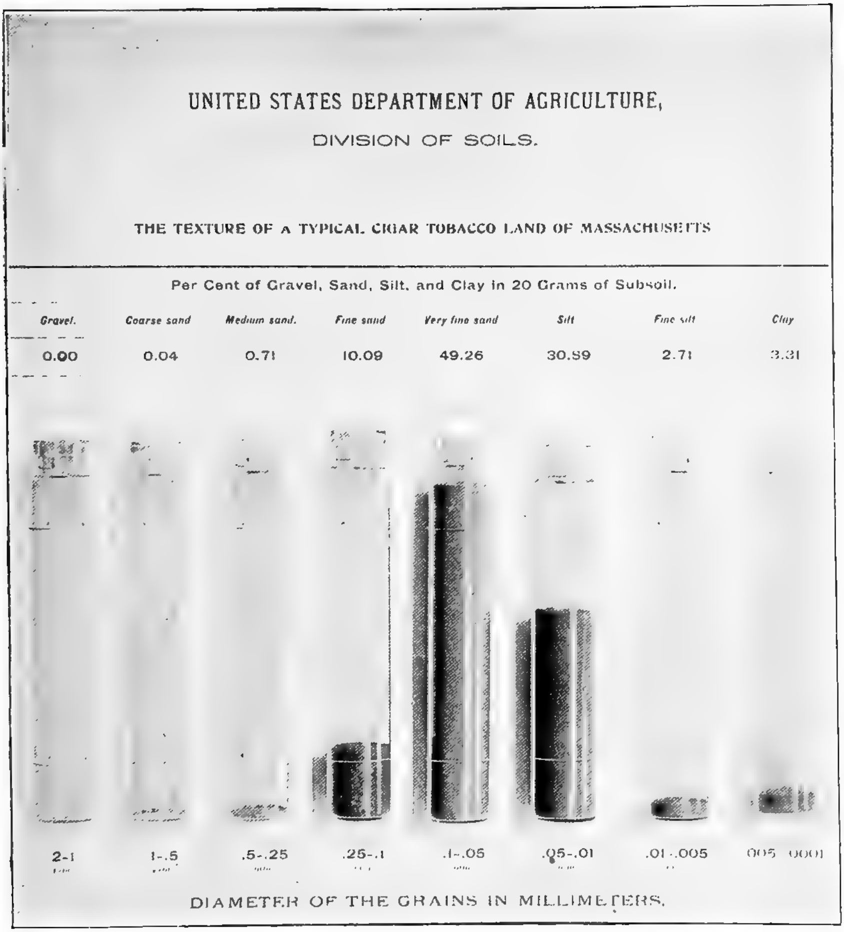
a River land and shaly limestone.
b Trenton limestone.

It will be seen from the table that the tobacco soils of the Connecticut Valley, both in Massachusetts and in Connecticut, contain on the average considerably less than 5 per cent of clay. These soils are too light in texture for any of the staple farm crops. They are adapted to the quick-growing spring vegetables, but are not used to any great extent for these crops, except immediately around the cities and larger towns. The conditions seem to be peculiarly adapted to this particular grade of wrapper leaf tobacco.

FASHION AS A FACTOR IN THE VALUE OF TOBACCO SOILS.

It must not be forgotten, however, that fashion has much to do in the consumption of cigars. Just at present the demand is for light wrappers and mild-smoking cigars. A few years ago the demand was for heavier cigars, and these light soils of Connecticut had little or no


UNITED STATES DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS.
THE TEXTURE OF A TYPICAL CIGAR TOBACCO LAND OF CONNECTICUT.
Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.
Gravel
Coarse sand
Medium sand
Fine sand.
Very fine sand
Silt
Fine silt
Clay
1.03
3.26
9.92
22.62
45.47
10.41
1.36
2.32
2-1
1-.5
05-.01
DIAMETER OF THE GRAINS IN MILLIMETERS.


UNITED STATES DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS.
THE TEXTURE OF A TYPICAL CIGAR TOBACCO LAND OF MASSACHUSETTS
Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.
Gravel. 0.00
Coarse sand 0.04
Medium sand. 0.71
Fine sand 10.09
Very fine sand 49.26
Silt 30.89
Fine silt 2.71
Clay 3.31
2-1
1-.5
.5-.25
.25-.1
.1-.05
.05-.01
.01-.005
.005-.0001
DIAMETER OF THE GRAINS IN MILLIMETERS.

value then for tobacco and were lying out as waste land. At that time the tobacco was grown mainly on the heavier soils and on the "meadow lands" of the Connecticut Valley. Strangely enough, there is little or no difference in the texture of these meadow soils compared with the light, sandy soils now used for tobacco, except that they usually contain a larger proportion of silt.

They are, however, probably by reason of their structure, very retentive of moisture and contain upwards of from 23 to 27 per cent of moisture, while the finest types of tobacco land in the Connecticut Valley contain only about 7 per cent. These meadow soils are therefore not used for tobacco at present, but if in the course of events the style should change and dark wrappers come into vogue, these lands will again be taken up and the present tobacco lands will have to be abandoned or used for other crops.

PENNSYLVANIA CIGAR TOBACCO LANDS.

The tobacco soils of Pennsylvania are confined mainly to the comparatively narrow belt bordering the Susquehanna River and to the broad expanse of limestone soils typically developed in York and Lancaster counties.

The better class of tobacco lands in Pennsylvania, and those which produce by far the finest wrapper leaf, are the light, alluvial soils along the river, many of them similar in texture to the tobacco soils of the Connecticut Valley. The main crop, however, of the Pennsylvania tobacco has been grown on the limestone soils of York and Lancaster counties. This is a continuation of the great limestone valley extending down through Maryland and Virginia and to the great area of the Trenton limestone formation in Ohio and Kentucky, forming the great blue grass region of these States upon which the white burley tobacco is at present grown.

This limestone soil, as it is exposed in the tobacco districts of Pennsylvania, is a strong clay soil, well adapted to grass, wheat, and corn. It forms one of the most productive areas in the State of Pennsylvania, and in this respect it is markedly different from the tobacco lands of the Connecticut Valley. There is considerable variety in the texture of the soils, as the limestone itself is not pure, but is mixed with shale. The amount of clay, therefore, in these Pennsylvania lands varies from about 13.8 per cent in the river soils and in the very shaly limestone soils to 29.27 per cent on the average in the pure limestone soils. (See Plate V.) The former grade of soils is preferred just at present to the very heavy ones, as they produce a better grade of wrapper leaf. By proper cultivation, close planting, and especially by proper fermentation and grading of the leaf, the quality of the filler grown on the heavy limestone soils could unquestionably be greatly improved.

It has not been feasible for agents of this division personally to examine the soils of the tobacco districts of New York. (See Plate VI.) A large number of soil samples were collected, however, through representative growers, whose names were furnished by the Tobacco Growers' Association. The samples were accompanied by full notes upon the character of the soil, the native vegetation, and the quality of the tobacco grown. A number of these soils have been analyzed, and the results show on the average that the soils contain rather more clay than the soils of the Connecticut Valley. They are much lighter in texture than the Pennsylvania tobacco soils.

OHIO CIGAR TOBACCO LANDS.

The cigar tobacco district of Ohio is situated in the southwestern part of the State and includes the country bordering the Miami River, Montgomery, Darke, and Preble counties forming the center of the district. The Miami Valley, in the tobacco area, is from 2 to 5 miles wide, level, and extremely fertile. Bordering the valley are upland rolling hills. Broad terraces extend back from the river in a number of places, giving second bottoms, beyond which come the great rolling red lands upon which tobacco is raised with great success. These soils are well drained, with numerous streams flowing out from between hills. Farther back on the level prairies the land is inclined to be wet and needs thorough underdrainage to be profitably cropped. Throughout the whole tobacco area, underdrainage is practiced to a large extent.

The soil is derived from drift material which has been worked over and modified by subsequent action of water. (See Plate VII.) The underlying rock is the Lower Silurian limestone shale, but it forms no feature of the surface, as it is covered by the drift material. There is quite a variety in the character of the soil, owing to the heterogeneous nature of the material from which it has been derived. The bottom soils are, as a rule, much lighter in character than the upland soils. The second and third bottoms, in cases where they occur, are level terraces. The soils vary much, the black prairie soil and the red silty soil predominating. The soils of the rolling uplands are more uniform in character. The timber is mainly sugar tree, and on this sugar-tree land the finest type of tobacco is produced. The sugar-tree soil is a thin, uniform, silty soil, with red clay or silty subsoil. The lower levels of this upland contain considerable areas of black land, which is considered the best land in the district for general agricultural purposes, but which produce too heavy a leaf and one of poor flavor, so that it is not desirable for tobacco culture. Wheat, corn, hay, and tobacco constitute the staple crops of the district, although on the sandy river lands truck and fruit growing are carried on to a large extent.

Three types of cigar leaf are raised in this district. The most popular at present is the Zimmer Spanish. This has small leaves about 12 inches long, of very fine texture and flavor. It produces about 1,000 pounds per acre. The old Ohio seed leaf is a very large, heavy leaf, 20 inches or more in length, and produces from 1,500 to 2,000 pounds per acre. This is little grown in the district at the present time. The

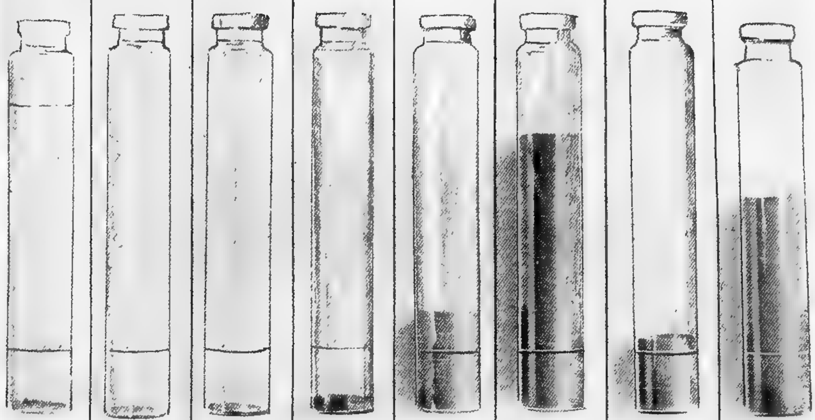
UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF SOILS.

THE TEXTURE OF A TYPICAL CIGAR TOBACCO LAND OF PENNSYLVANIA

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil

Gravel.	*Coarse sand.*	*Medium sand.*	*Fine sand*	*Very fine sand*	*Silt.*	*Fine silt*	*Clay*
0.68	0.78	0.91	2.47	13.89	34.23	9.79	29 27



2-1 mm	1-.5 mm	.5-.25 mm	.25-.1 mm	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.

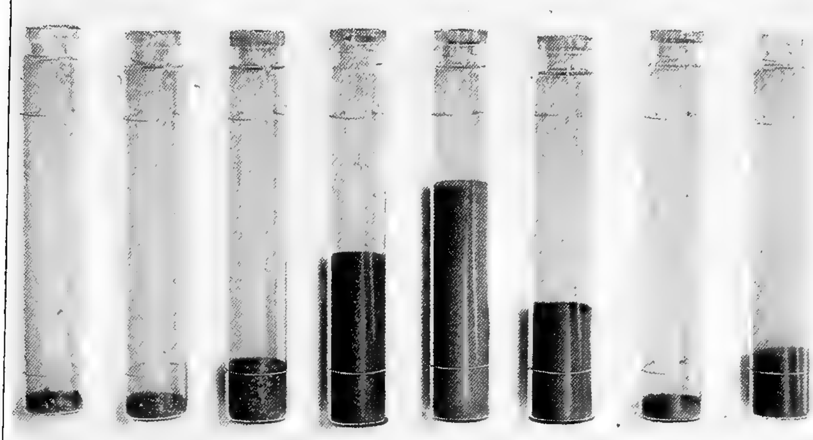
UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF SOILS.

THE TEXTURE OF A TYPICAL CIGAR TOBACCO LAND OF NEW YORK.

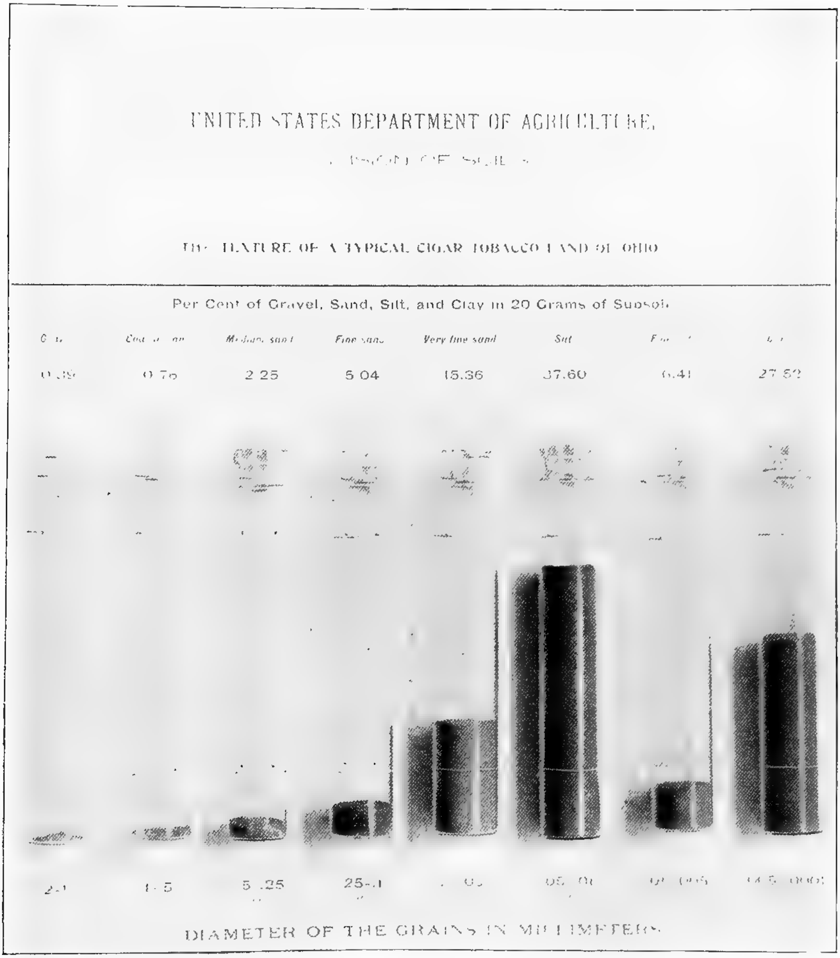
Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt.*	*Fine silt.*	*Clay*
1.94	2.80	9.02	24.47	32.52	15.09	3.09	7.43



2-1 mm	1-.5 mm	.5-.25 mm	.25-.1 mm	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.



Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil
Fine sand
Very fine sand
Silt
2.25
5.04
15.36
37.60
1-.5
.5-.25
.25-.1
DIAMETER OF THE GRAINS IN MILLIMETERS

Little Dutch has a thick, short, narrow leaf which produces about 1,200 pounds per acre and was at one time very extensively grown. These tobaccos are grown almost exclusively for filler purposes.

It will be seen from the table already given that these soils have a large percentage of clay.

WISCONSIN TOBACCO SOILS.

The Wisconsin tobacco is used both as a wrapper and filler leaf to some extent, but it is known in the markets as a binder State. The character of the leaf is midway between the Connecticut wrapper and the Pennsylvania filler.

The tobacco is grown in the southern part of the State on the prairies and oak openings. The prairies are a dark, rich loam, resting on a rather heavy silt or clay. The oak openings have a loam lighter in color but about the same in texture. Both are gently rolling and, as a rule, have good surface and under drainage. In texture the Wisconsin lands come between the Connecticut and the heavier limestone soils of Pennsylvania. (See Plate VIII.)

SOILS OF THE SOUTHERN CIGAR TOBACCO DISTRICTS.

Tobacco has been grown for many years in Florida, especially in the western part of the State. The tobacco grown there is mainly the Cuban type of cigar wrapper and filler, with some Sumatra lately introduced. The recent scarcity of Habana tobacco has given a great impetus to the cultivation of the crop in Florida, and very extensive arrangements have been made to introduce it to a large extent in the central part of the peninsula.

The accompanying table gives the average texture of the cigar tobacco soils of the Southern States:

Mechanical analyses of subsoils.

Number of samples.	Locality.	Grade of leaf.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.)	Coarse sand (1–0.5 mm.)	Medium sand (0.5–0.25 mm.)	Fine sand (0.25–0.1 mm.)	Very fine sand (0.1–0.05 mm.)	Silt (0.05–0.01 mm.)	Fine silt (0.01–0.005 mm.)	Clay (0.005–0.0001 mm.)
			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
20	Florida, peninsula	Main-crop wrapper, binder filler. Sucker-crop filler.	0.62	1.73	0.26	2.60	18.94	51.53	18.95	1.33	0.59	3.21
4	Florida, Gadsden County.	Same grades *a*	.58	2.68	.68	4.85	20.03	45.53	14.93	4.15	.80	5.15
4	do	Same grades, subsoil.	1.18	5.69	.54	1.94	8.81	35.15	13.39	3.37	1.07	29.30
3	Texas	Same grades	.23	.46	1.63	6.58	24.55	37.05	14.16	8.90	1.59	4.70
1	California	Wrapper and filler.	1.28	3.91	2.94	5.49	19.44	27.33	12.85	13.37	2.18	10.77
8	Sumatra	Wrapper	7.48	15.41	1.41	4.39	9.95	16.15	17.17	19.11	4.35	5.00
6	Cuba (Vuelta Abajo).	Wrapper and filler.	.74	3.80	4.06	4.62	8.28	21.67	43.09	6.53	1.82	5.69
4	Cuba (Remedios).	Same, heavier	5.17	10.01	1.31	.36	.52	4.51	14.97	21.24	9.37	32.32

a A light loam, averaging 12 to 18 inches deep, overlying the red clay.

CIGAR TOBACCO SOILS OF WESTERN FLORIDA.

The soils of the older Gadsden County district in the western part of the State are very different from any others which occur in Florida. They are the characteristic "red-land" soil of the Lafayette formation, similar to those found at Wedgefield and Aiken, S. C., which extend south through Georgia and form some of the western counties of Florida, with Quincy as a center. The soil is a light loam resting on a very strong red clay. The clay is exposed in all cuts and in the washings of the land, and is usually found from 8 to 18 inches below the surface. The country is quite rolling, well wooded with hard-wood trees, and in the early spring it has the fresh green appearance of the country in the Valley of Virginia and in the tobacco area of Pennsylvania.

Both the Cuban and Sumatra types of tobacco are grown here, and both are used for wrappers as well as fillers. Unlike the imported Sumatra tobacco, the tobacco grown in Florida from Sumatra seed loses much of its bitter taste, while the sucker crop and inferior leaves are cured up with more body and are much better adapted to filler purposes.

A single plantation in Gadsden County had last year 900 acres in tobacco and, with the crops bought of the farmers in the surrounding country, the company owning the plantation cured and packed upward of 2,500 bales. The season is so long that two crops of tobacco can be produced in the same year, or two or three sucker crops can be grown after the main cutting has been taken. The sucker crop is stronger, heavier, and darker, and is used only as a filler.

It will be seen from the table that these red subsoils contain about 30 per cent of clay, and therefore compare in texture with the soils of the Ohio seed leaf district and with the stronger soils of Pennsylvania. The top soil, however, is quite a light loam, and the character of the land as a tobacco soil depends largely upon the depth and character of the red-clay subsoil. These lands are notable in another respect, which seems to be characteristic of this formation generally, namely, they maintain on an average only about 8 or 10 per cent of moisture against 20 to 22 per cent maintained by the Pennsylvania and the Ohio lands.

CIGAR TOBACCO SOILS OF THE FLORIDA PENINSULA.

Outside of this area in western Florida most important developments have recently been made around Ocala, Bartow, and Fort Meade. At Fort Meade particularly there is a well-organized company, managed by Cubans, with a large area in tobacco. The first crop was made last year. This was cured and fermented according to the Cuban processes, and without waiting to mellow with age, as is necessary to bring out the finest qualities of a tobacco, the crop was sold at Tampa for a very satisfactory price.

Tobacco growing on the peninsula is essentially a new industry, and comparatively little experience has been available except what has

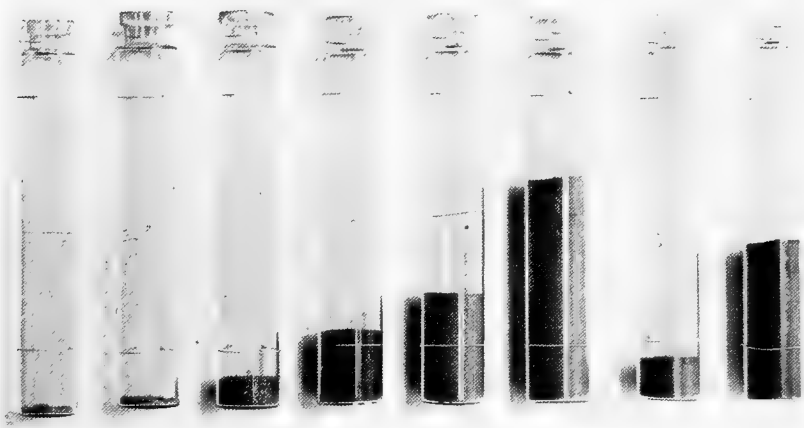
UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF SOILS.

THE TEXTURE OF A TYPICAL CIGAR TOBACCO LAND OF WISCONSIN.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	*Coarse sand.*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt*	*Fine silt.*	*Clay*
0.59	1.09	4.98	10.34	15.68	31.04	6.01	22.76



2-1 mm	1-.5 mm	.5-.25 mm	.25-.1 mm	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.

been collected during the past year. The industry has been developed upon the post-oak lands around Ocala, which are considered the best type of tobacco lands in that locality, and upon the hammock lands at Bartow and Fort Meade. There are large areas of these soils in the State which can be developed through the tobacco interest, and there is every reason to believe that the venture will be very successful. There is no reason to doubt that many of the pine lands are well suited to tobacco.

There is very little difference in the texture of the post-oak lands, the hammock lands at Fort Meade, and the pine lands. The difference in the soil which causes the distribution in the forest growth appears to be mainly due to the difference in the water content of the soils, as will be explained in another place. The soils are all very light and sandy. It will be seen from the table that they contain on an average less than 4 per cent of clay and less than 6 per cent of silt, fine silt, and clay. They contain over 50 per cent of "fine sand," so that they are relatively rather coarse and open. Notwithstanding this open texture, the hammock soil at Fort Meade contains on an average about 8 per cent of water throughout the season, which is about as much as the tobacco lands of the Connecticut Valley contain. This water content, moreover, is for some reason more uniform, and the land can go for some time without rain with no serious injury to the crops. Nevertheless, the planters have been greatly benefited by judicious systems of irrigation through overhead sprays. By thus keeping the plants continually and rapidly growing the crop will mature in forty-five days from the time the plants are set out. On account of the length of the season tobacco can be grown almost continually through the year, and crops can be set out almost every month in the year. Usually two or three crops are made and two or three sucker crops are produced. There is undoubtedly a vast area of land in Florida suited to tobacco, and the climate is unquestionably favorable for the production of a very fine quality of leaf. A very intelligent method of growing and fermenting is being practiced, and there is no reason why the industry should not be successful.

For a great commercial success there must be a large quantity of tobacco for the manufacturers to depend on in maintaining particular brands of cigars. The method of curing and sweating can be more economically and successfully done in large bulk than in small quantities. The experience of the growers in Cuba and Sumatra, that the tobacco grown near the water has an inferior burn, must be given due consideration in extending the industry toward the coast and developing it in the lake regions of the State.

It has not been feasible for agents of the Department to make a personal investigation of the soils of the new tobacco districts which are being developed in Texas and in southern California. A number of samples of soil have been received from prominent growers from both

States and have been analyzed in the Division. The results as given in the table show that the soils agree very well with the finer grade of cigar tobacco lands. The general climatic conditions, however, are different, and great care and judgment should be used in selecting suitable locations for the industry.

BRIGHT TOBACCO LANDS.

The bright yellow tobacco used for cigarettes, plug wrappers, fillers, and cutting is grown mainly in Virginia, North Carolina, South Carolina, and East Tennessee. (See Plate IX.) It is, however, produced in smaller quantities in several of the other Southern States. Wherever it is grown the industry is confined to a certain type of soil. The conditions in Granville and Buncombe counties, N. C., and around Danville, Va., are typical of the conditions upon which the industry is based.

The typical bright tobacco land consists of a loose, porous sand, containing not more than 8 or 10 per cent of clay. This sand must be at least 12 inches deep. Many areas are cultivated in which the sand extends to a depth of 5 or 10 feet or more, and a very fine quality of tobacco is produced. As a general rule the less clay the soil contains and the deeper the sand the finer the quality of the tobacco, providing it keeps growing continuously. The trouble with such very light soils is that they produce but a small yield per acre and there is danger of drought, which would check the growth of the plant and cause the leaves to thicken. It is for this reason, therefore, that it is preferred to have the sand underlaid at a depth of 18 to 22 inches by a heavier clay, which tends to conserve the moisture supply of the soil and renders the plant less subject to the injurious effects of what would otherwise prove a severe drought.

The clay which underlies the bright tobacco lands of Virginia and North Carolina is the same as that upon which the heavy manufacturing and export tobacco is grown. Where this clay is exposed to the surface the heavy type of tobacco is produced; where it is covered from 12 to 20 inches with fine-grained sand the bright tobacco is produced the most profitably.

The country throughout these regions is generally quite rolling, with numerous "draws," or natural ditches, and streams, so that the land is well drained. The sandy covering is usually found on the ridges or slightly elevated plateaus, while the heavy clay may be exposed within a few feet, and the two types of tobacco successfully grown upon the same farm. For this reason it has never been easy to define the areas of the two types of tobacco, for they are both grown in the same counties and frequently on the same farm.

The accompanying table shows an average of 44 samples of the subsoils of the bright tobacco lands which have been examined, and they contain about 8 per cent of clay. This is quite uniform, the extreme range for profitable tobacco culture being probably between 6 and 12

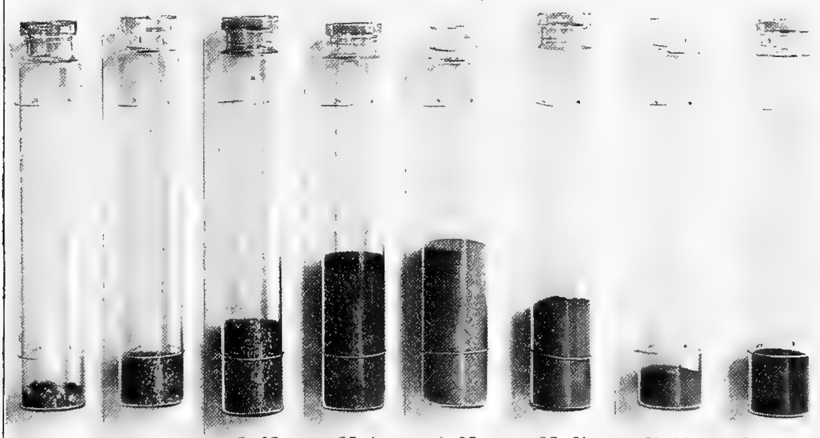
UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF SOILS.

THE TEXTURE OF A TYPICAL BRIGHT TOBACCO LAND OF VIRGINIA AND NORTH CAROLINA.

Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel.	*Coarse sand.*	*Medium sand.*	*Fine sand.*	*Very fine sand.*	*Silt.*	*Fine silt.*	*Clay*
2.57	6.39	13.67	22.02	23.45	14.08	5.43	8.23



2-1 mm	1-.5 mm	.5-.25 mm.	.25-.1 mm	.1-.05 mm	.05-.01 mm	.01-.005 mm	.005-.0001 mm

DIAMETER OF THE GRAINS IN MILLIMETERS.

per cent. The character of the red clay subsoil is also shown for the manufacturing tobacco district of Virginia:

Mechanical analyses of subsoils.

Number of samples.	Locality.	Description.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
44	Virginia and North Carolina.	Bright yellow...	1.10	2.24	2.57	6.39	13.67	22.02	23.45	14.08	5.43	8.23
55	Kentucky and Tennessee.	Export	2.23	3.00	.39	.56	.73	1.93	9.50	52.50	6.28	22.59
30	Kentucky and Ohio.	White burley...	3.48	4.42	.64	1.63	1.44	1.22	7.04	39.77	9.36	31.62
21	Virginia	Manufacturing .	5.55	7.87	1.22	2.05	3.47	6.94	9.45	11.29	7.67	44.38

As the relation of the physical properties of the soil is not thoroughly understood or practically recognized by the growers, a large amount of land is now cultivated in bright tobacco which is not suited to this plant and which does not produce a good grade. On the other hand, there are large areas not at present under cultivation which could be developed into very fine tobacco lands. The typical bright tobacco soil is of little value for any of the staple farm crops, although, when suitably located near transportation lines, it is admirably adapted to the production of early vegetables, watermelons, and sweet potatoes.

MANUFACTURING TOBACCO LANDS OF VIRGINIA AND NORTH CAROLINA.

Before the development of the white burley industry the strong red-clay soils around Charlottesville, Lynchburg, and Danville, Va., and in Granville and neighboring counties of North Carolina were extensively used for the production of the typical Virginia manufacturing and export tobacco. These areas are located mainly on the gabbro, gneiss, and Lafayette clays. The material is quite uniform, the subsoils containing from 30 to 50 per cent of clay. (See Plate X.) They are very productive and are well suited to the staple farm crops, such as grass, wheat, and corn. Since the introduction of the White Burley tobacco, however, there has been a very noticeable decrease in the acreage in Virginia, especially of the soil adapted to the heavier types of tobacco, and the cultivation of tobacco on these lands has been almost abandoned. The industry is confined now principally to small areas along rivers, streams, or creeks and upon recent deposits which can not well be referred to any of the older geological formations and which can not well be examined without a detailed examination of the larger part of the State.

The same remark holds true in regard to the tobacco industry in North Carolina. A great change has taken place very recently, and the acreage devoted to the heavier type of tobacco has been considerably reduced. These heavy clay lands are being used for other crops, and the tobacco is grown upon limited areas in certain districts where the quality of the tobacco produced is such as to make it reasonably profitable. Here, again, it is impossible to make any statement in regard to the tobacco district without making a detailed study of the soils of the State. There seems to be no general type of soil. The tobacco grown upon the soil which was formerly cultivated most extensively is no longer profitable.

The table shows that these soils, which a very few years ago would have been considered the typical manufacturing tobacco land, contain on an average over 40 per cent of clay and have thus a larger content of clay than the soils of any other tobacco district.

THE WHITE BURLEY TOBACCO LANDS OF KENTUCKY AND OHIO.

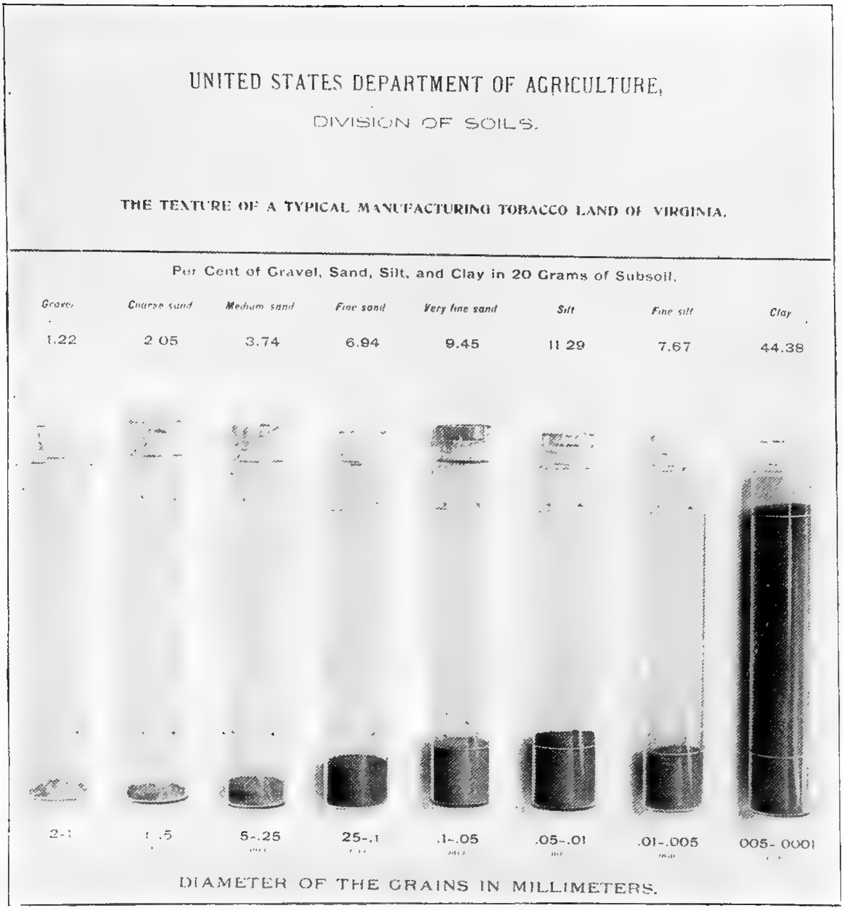
The white burley tobacco is confined to the well-marked type of soil of the Lower Silurian limestone in central and north central Kentucky and the adjacent counties of Ohio. This embraces the blue grass region of Kentucky, and it is upon these fine, fertile, blue grass soils that the white burley is grown. (See Plate XI.)

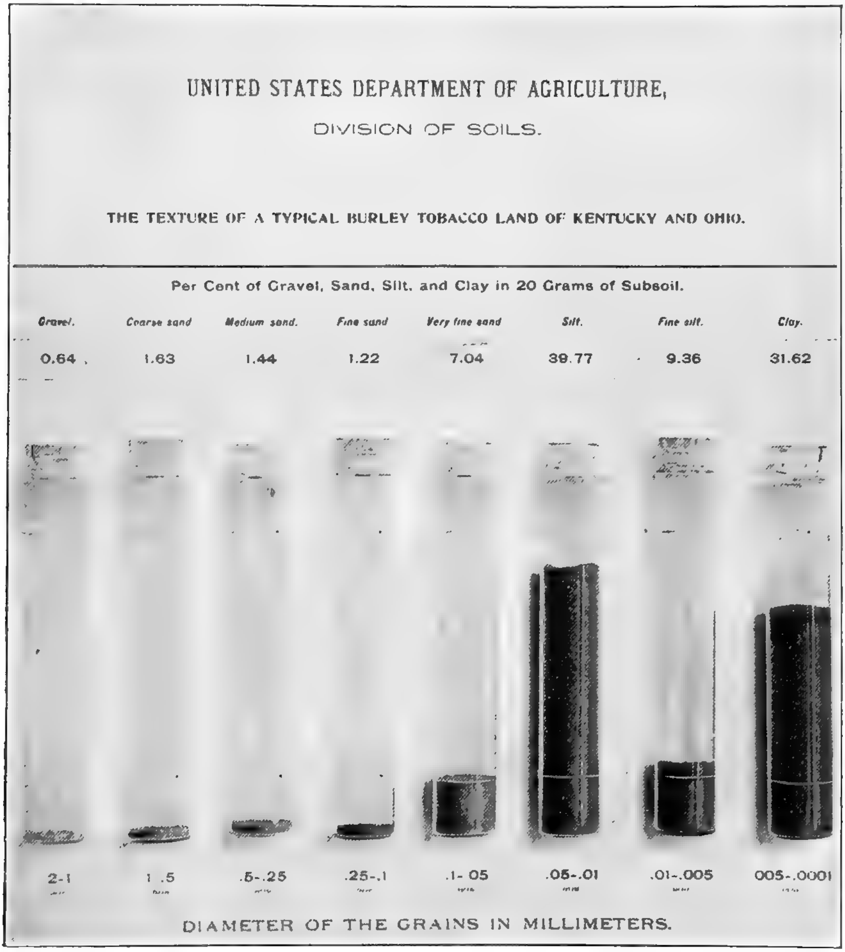
The country has the general appearance of an old limestone region, generally rolling and with frequent depressions, sinks, and caves. The hills, 400 to 500 feet high, bordering the Ohio River and extending from 6 to 10 miles back, are generally steep, and fields are often cultivated in tobacco with slopes as great as 45 degrees. The valleys are narrow, winding, and V-shaped, and no bottom lands are found excepting along the larger rivers and streams. The country back from the hills on the Ohio side is generally rolling. The drainage is excellent.

The tobacco lands on the Ohio side are all within the hills on the Ohio River and confined to two kinds of soil, popularly known as the "sugar-tree land" and "beech land." The beech lands lie low in the valley and are inclined to be wet, and do not produce the finest quality of leaf. The sugar-tree lands lie well up in the valleys and are considered the typical white burley soil. Back from the hills, in Ohio, the soil becomes white, wet, and "crawfishy" and does not produce a fine quality of burley. These flat lands are of drift origin, timbered with white oak, and usually need to be underdrained in order to produce well.

In Kentucky the tobacco area is confined to the Trenton and Hudson River limestones. Phosphatic limestone is frequently met with, while chert occurs only sparingly through the area.

The soils are all heavy clay of a uniform deep red color. The depth of the soil varies considerably, the rocks outcropping in many places, especially on the hillsides. Around Lexington the rock is on the average about 6 feet below the surface, while in the northern counties it is at a greater depth than this. The top soil is of light, loamy character, not inclined to form into clods when properly cultivated. The soil is adapted to grass, wheat, and corn, and has made famous the world over the blue grass region of Kentucky. It is seen from the table (page 25) that the subsoil contains on an average about 30 per cent of clay.


UNITED STATES DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS.
THE TEXTURE OF A TYPICAL MANUFACTURING TOBACCO LAND OF VIRGINIA.
Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.
Gravel
Coarse sand
Medium sand
Fine sand
Very fine sand
Silt
Fine silt
Clay
1.22
2.05
3.74
6.94
9.45
11.29
7.67
44.38
2-1
5-.25
25-.1
.1-.05
.05-.01
.01-.005
005-.0001
DIAMETER OF THE GRAINS IN MILLIMETERS.


UNITED STATES DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS.
THE TEXTURE OF A TYPICAL BURLEY TOBACCO LAND OF KENTUCKY AND OHIO.
Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.
Gravel. Coarse sand Medium sand. Fine sand Very fine sand Silt. Fine silt. Clay.
0.64 1.63 1.44 1.22 7.04 39.77 9.36 31.62
2-1 1 .5 .5-.25 .25-.1 .1-.05 .05-.01 .01-.005 .005-.0001
DIAMETER OF THE GRAINS IN MILLIMETERS.

EXPORT TOBACCO LANDS OF KENTUCKY AND TENNESSEE.

The dark, heavy varieties of tobacco adapted to the export trade are extensively grown in western Kentucky and Tennessee on silty soils which are quite fertile in character. The whole area is divided into a number of districts, such as Clarksville, Hopkinsville, Jackson's Purchase, and the Green River district, but the character of the soil is quite uniform in all of these; the class of tobacco grown is generally the same. In each district the types of tobacco adapted to the foreign markets are grown, the types appearing to depend less upon the character of the soil than upon the character of the season, the cultivation, and curing of the crop.

The general character of the country is level or gently rolling, with broken and hilly country along the large water courses. Much of this land was formerly devoid of forest growth and called barrens. It was a prairie region, with trees only along the water courses, and prairie fires are supposed to have annually swept over the country. Since the country has become settled and the large fires prevented, a luxuriant forest growth of hickory and oak has covered the land. The soils are classed by Safford as "rich barrens." The term "barrens" is not to be taken literally to mean poor soil.

The counties of Kentucky bordering the Tennessee line are generally level, with occasional stretches of rugged country along the water courses, but with a soil of quite uniform texture. The southern boundary of the tobacco area is the Cumberland River, while the northern boundary is the carboniferous hills of Kentucky. The tobacco district stretches around these hills, following the subcarboniferous strata as far as the Ohio River on either side.

SOILS ARE HALF SILT.

The soils are mainly derived from the St. Louis group of the subcarboniferous, which are mainly limestone. (See Plate XII.) The disintegrated material is so thick that the rock is seldom exposed, except where the material has been recently eroded. The drainage is excellent, and numerous sinks and caves are found through the country. The soil, whether upland or bottom, level or hilly, is usually of a decided silty character, closely approaching loess in texture. The subsoil has a typical bright red color, which extends to a considerable depth. Where this red color changes to a pale yellow or white, the land becomes crawfishy and can only be profitably cultivated after underdrainage. The lack of color indicates a deficient drainage within recent times and is due to the deoxidation of the iron compound in the decay of organic matters and the absence of sufficient oxygen from other sources to provide for the proper oxidation of the organic matter.

It will be seen from the table that these soils contain on an average about 50 per cent of silt. It ranges from about 40 to 60 per cent, some samples exceeding even this latter figure. With all such silty soils great care has to be taken in their cultivation. They are naturally quite fertile, but deteriorate very rapidly and excessively unless the fertility is maintained by judicious methods of cultivation and of cropping. Many of these tobacco soils have been run down with constant cropping in tobacco, but some of the worst cases have recently been brought up by rotation with wheat, corn, and clover, together with a judicious application of fertilizers, especially phosphatic manures. The value of careful tillage is becoming more apparent in the whole area, and it is generally recognized now that the quality of the tobacco and the price it brings on the market can be very materially influenced by the kind and condition of the cultivation.

The soils of the Lower Green River district lie within the carboniferous strata along the Green River, and, although these are underlaid with sandstone, the soil proper presents the uniform silty character of the other export tobacco districts.

The Jackson's Purchase region, lying between the Tennessee and Mississippi rivers, is made up mainly of loess and loam, and has the same silty character as the other districts and produces essentially the same type of tobacco.

The accompanying diagram (Plate XIII) illustrates graphically the relative proportion of the sand, silt, and clay in the soil adapted to different classes and types of tobacco, and shows, upon careful study, a marked relation between the texture of the soil and the grade of tobacco produced. A detailed statement of the analyses upon which these summaries are based is given in the table at the end of the bulletin.

THE RELATIVE WATER CONTENT OF TOBACCO SOILS.

It has been stated that a classification can be made of the tobacco soils in accordance with their texture, as this determines to a large extent the water content of the soils and the amount of water at the disposal of the crop. The texture is not the sole factor, however, which determines the water content; so it has been necessary to keep actual records of the water content of some of the principal tobacco soils. Only preliminary work has been started in this, as a satisfactory method for the ready determination of the water content of the soils has only just been completed. So far as these records have been taken they show a very great difference in the soils adapted to the different classes of tobacco, and in a general way agree with the texture of the land.

The earlier records were made by taking a sample of soil in a brass tube, driven from the surface of the ground to a depth of 12 inches. The sample was transported to the laboratory without any evaporation and there dried at a temperature of 110° C. and the amount of water determined by the loss in weight. The investigations this year have been made by the electrical method described in Bulletin No. 6.

These records must be maintained through a number of years before reliable data can be established to show the average water content of the soils, as well as to show the normal variations which may occur in

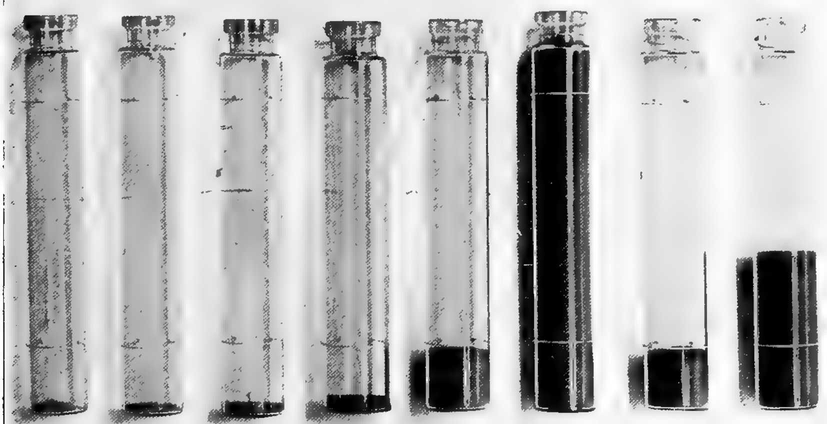
UNITED STATES DEPARTMENT OF AGRICULTURE,

DIVISION OF SOILS.

THE TEXTURE OF A TYPICAL EXPORT TOBACCO LAND OF KENTUCKY AND TENNESSEE.

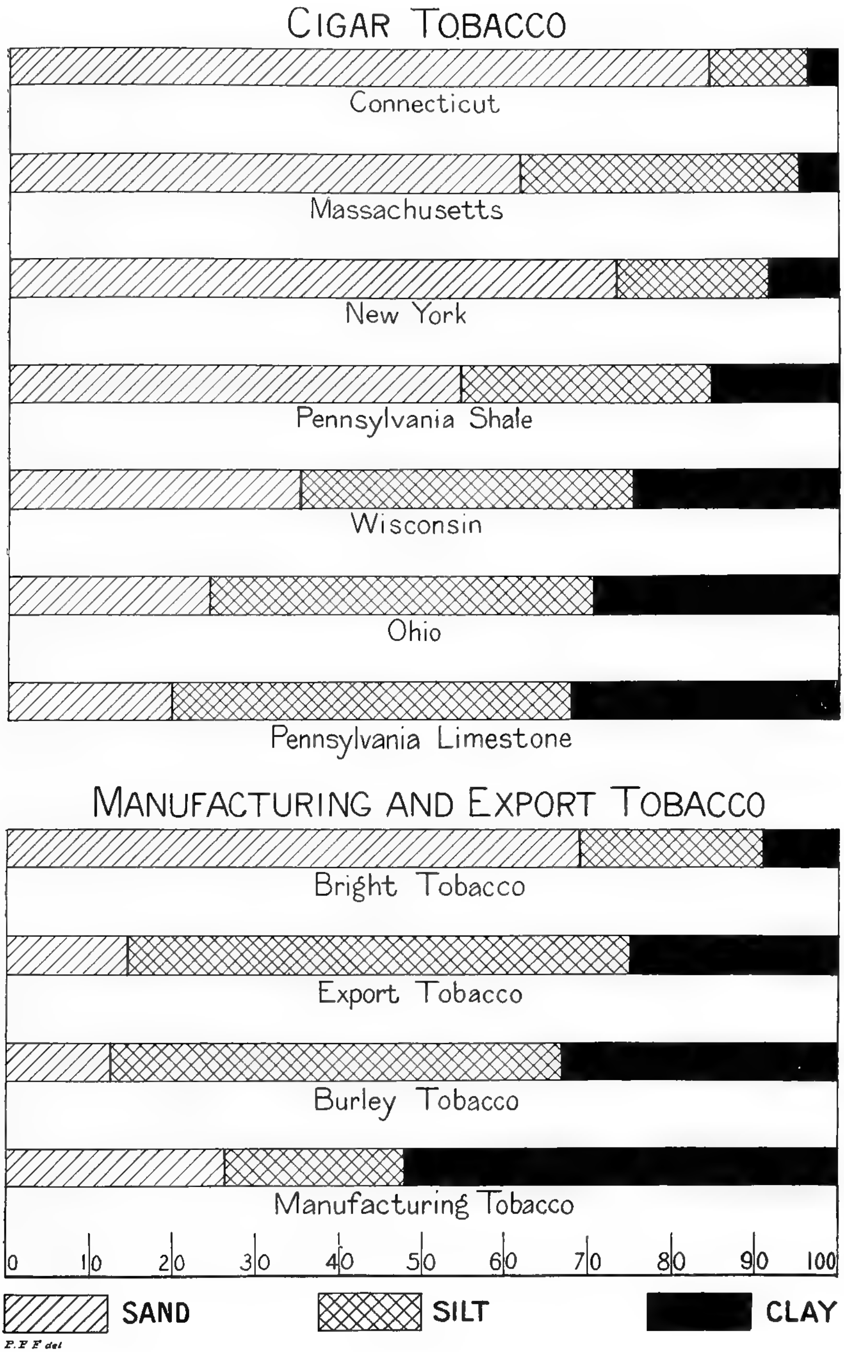
Per Cent of Gravel, Sand, Silt, and Clay in 20 Grams of Subsoil.

Gravel	*Coarse sand*	*Medium sand.*	*Fine sand.*	*Very fine sand*	*Silt*	*Fine silt*	*Clay.*
0.39	0.56	0.73	1.93	9.50	52.50	6.28	22.59



2-1 mm	1-.5 mm	.5-.25 mm	.25-.1 mm.	.1-.05 mm	.05-.01 mm	01-.005 "	005 000

DIAMETER OF THE GRAINS IN MILLIMETERS.


CIGAR TOBACCO
Connecticut
Massachusetts
New York
Pennsylvania Shale
Wisconsin
Ohio
Pennsylvania Limestone
MANUFACTURING AND EXPORT TOBACCO
Bright Tobacco
Export Tobacco
Burley Tobacco
Manufacturing Tobacco
0
10
20
30
40
50
60
70
80
90
100
SAND
SILT
CLAY
P. F. F. del

the water content without danger to the plant. At the same time sufficient work has been done to give an idea of the mean relative water content of these different soils, under the meteorological conditions which have existed. This water content is sensibly the same for several of the soils in any one season.

The amount of water a soil contains depends largely, as has been stated, upon the texture and structure and is influenced of course by the character of the season. It varies from day to day, and these variations are exceedingly important in their effects upon the crop. The term "mean water content," therefore is only to be used as a measure of the relative water-holding capacity of the soil under similar meteorological conditions.

MEAN WATER CONTENT OF THE NORTHERN CIGAR TOBACCO SOILS.

Tobacco soils of the best grade in the Connecticut Valley maintain on an average about 7 per cent of water throughout the season. There are many soils cultivated in tobacco which average 10 or 12 per cent, but these do not produce a tobacco leaf of the finest texture and most desirable quality for the present market. On the other hand, there are soils cultivated in tobacco which maintain less water than this, and while in favorable seasons, when the tobacco is kept constantly growing, they produce a very fine and delicate leaf, it is not on the whole a safe or economical condition under which to grow the plant on account of the small yield per acre and the injury liable to occur in dry seasons. The meadow lands of the Connecticut Valley, which were formerly cultivated in tobacco when a dark, heavy leaf was in demand, contain on an average from 20 to 28 per cent of water. As already stated, these soils are entirely unfit for the production of the grade of tobacco necessary to meet the present market demands.

The tobacco soils of Pennsylvania, as already explained, are heavier than those of the Connecticut Valley and maintain on an average about 18 per cent of water. The present season has been unusually wet, and the average this year has been 4 to 5 per cent higher, but as a result of three years' observations 18 per cent can safely be taken as the mean water content of the average tobacco soil of the limestone area of the Pennsylvania district.

Soils which produce the best wrapper leaf in Pennsylvania are those which have the lightest texture and contain the smallest water content, while the heaviest limestone soils maintain on an average 22 to 23 per cent of water and produce mainly a heavy, strong filler leaf.

The soils of the tobacco district of Ohio are as heavy in texture as the limestone tobacco lands of Pennsylvania. They have maintained on an average the present season rather more than 27 per cent of water. It is probable that the mean water content of these soils in an average season would amount to about 23 to 24 per cent of water. The tobacco grown under these conditions is used almost exclusively as a filler leaf.

No records have been kept of the water content of the tobacco soils of New York or Wisconsin.

It is unquestionably true that the texture of the soil and the meteorological conditions, with the resultant water content, determine to a marked extent the character and grade of leaf which can be produced. In this, as in all other agricultural lines, the aim should be to recognize the conditions and adopt the crop, the method of cultivation or fermentation, and the grade of leaf which those conditions are best adapted to produce. If the general character of the soil in a locality is adapted to the wrapper leaf, use only such soils as may be reasonably expected to give the best wrapper leaf. If, on the contrary, the soils of the district are adapted only to filler leaf, use only such of the soils as are best adapted to this grade and plant, cultivate, manure, and ferment the crop for the specific purpose of producing a filler leaf of superior quality. Most of the tobacco soils of the Northern States will not produce equally good fillers and wrappers.

WATER CONTENT OF THE FLORIDA TOBACCO SOILS.

Records have been kept during the present season of the moisture conditions in the soils of the Gadsden County district of West Florida and of the newer tobacco district of Fort Meade, in the peninsula. The mechanical analyses showed that the tobacco land in western Florida consisted of a light loam about 12 inches deep resting on a heavy red clay which is naturally well drained. The hammock soil of Fort Meade is, on the other hand, a very light sandy soil, extending down to a very considerable depth. Both soils produce a hard wood growth. Strange to say, in spite of the great difference in the texture of the subsoil, the soils of these two localities have maintained during the present season almost identically the same amount of moisture. The average water content of the soil at Fort Meade, for a period of four months, was 8.6 per cent, while the mean water content of the soil at Quincy for the same time was 8.26 per cent. It is a surprising thing to find that these soils maintain about the same amount of water, but this is in line with the general facts that the hammock soils of Florida maintain very much more water than would be expected from their texture, or than is maintained by soils of similar texture further north along the Atlantic Coast. This matter of the relatively large amount of the water content of the hammock soils of Florida will be discussed in a separate bulletin.

No records have been kept of the moisture conditions in the tobacco soils of Texas or of California, and unfortunately none have been kept in the tobacco soils of Sumatra and Cuba.

WATER CONTENT OF THE SOILS OF THE MANUFACTURING AND EXPORT TOBACCO DISTRICTS.

As in the northern cigar tobacco districts, it will be seen that the texture of the soil and the water content appear to determine the type of tobacco produced. The typical soils for the bright yellow tobacco of Virginia, North Carolina, and East Tennessee maintain on an average about 7 per cent of water. Where the soils contain less than this the leaf is inclined to be thinner in texture and to have a better color, but the yield per acre is small, and the most economical conditions on the whole are maintained by these soils having from 7 to 8 per cent of clay and maintaining on an average about 7 or 8 per cent of water. As the soil becomes heavier in texture and the amount of water increases, other grades and types of tobacco are produced.

The export tobacco lands of Kentucky and Tennessee contain about 22 or 23 per cent of clay, and as a characteristic feature they contain from 40 to 60 per cent of silt. These soils contain on an average about 15 per cent of water, although the soil at Hopkinsville, Ky., this year, which had an unusually wet growing season, maintained on an average about 3 per cent more than this.

The characteristic soil of the limestone area of Kentucky, adapted to the white burley tobacco, as the result of several years' investigation, may be said to maintain on an average about 20 per cent of water. The present season being unusually wet, the water content in the soil at Lexington, Ky., was about 3 per cent above the normal.

Records have not been kept in the manufacturing tobacco soils of Virginia, but from investigations which have been made on adjacent lands it is probable that the mean water content of these soils, having as much as 40 per cent of clay, will not be far from 20 or 22 per cent of moisture.

RECORDS AS A BASIS FOR IRRIGATION.

The object of the daily record of moisture in the soil is not only to determine the average amount soils contain, but to determine the normal as well as the extreme variation. It is known, for example, that in the white burley limestone soil at Lexington, Ky., if the water content is maintained for any length of time above 25 per cent the land will be too wet for crops, while, on the other hand, if it falls to 15 per cent it will be too dry, and anything less than this will constitute a drought. The extent and duration of the drought will be apparent if the results are plotted on cross-section paper. It is possible from such records, therefore, to show the character of a season. The methods of cultivation should have for their prime object the maintenance of the water supply above the line of drought, so that the growth of the plant shall receive no check. If this can not be done by the ordinary method of cultivation, irrigation must be resorted to upon such occasions, if the crop is to be maintained in its best condition.

It will require years to establish satisfactory normals for any soil, but the normal variation which may occur without detriment to the crop can probably be approximately established in a very much shorter time. This line of work is being vigorously pushed now.

TABLES OF THE WATER CONTENT OF TOBACCO SOILS.

Following are the tables showing the records of the water content of tobacco soils so far obtained.

Cigar tobacco land.

POQUONOCK, CONN.

Day.	July, 1895. Moisture. *a*	Day.	July, 1895. Moisture. *a*	Day.	July, 1895. Moisture. *a*	Day.	July, 1895. Moisture. *a*
	Per cent.		*Per cent.*		*Per cent.*		*Per cent.*
1	8.8	9	12.6	17	8.8	25	8.2
2	8.7	10	12.4	18	8.9	26	9.2
3	9.0	11	11.4	19	8.6	27	10.1
4	9.6	12	11.4	20	8.5	28	10.4
5	10.5	13	13.4	21	8.9	29	9.5
6	11.1	14	14.4	22	9.4	30	8.9
7	11.2	15	13.1	23	9.6	31	8.7
8	11.4	16	11.1	24	8.5		

a At depth 0–12 inches.

WINDSOR, CONN.

Day.	May, 1897. *a* Moisture.	May, 1897. *a* Rain.	June, 1897. *a* Moisture.	June, 1897. *a* Rain.	July, 1897. *a* Moisture.	July, 1897. *a* Rain.	Day.	May, 1897. *a* Moisture.	May, 1897. *a* Rain.	June, 1897. *a* Moisture.	June, 1897. *a* Rain.	July, 1897. *a* Moisture.	July, 1897. *a* Rain.
	Per ct.	*Inch.*	*Per ct.*	*Inch.*	*Per ct.*	*Inch.*		*Per ct.*	*Inch.*	*Per ct.*	*Inch.*	*Per ct.*	*Inch.*
1	....	......	12.1	Trace	13.3	......	17	14.4	......	10.3	......	10.2	......
2	....	......	11.6	......	12.5	Trace	18	14.3	......	10.7	0.13	9.9	......
3	....	......	11.1	......	12.4	0.01	19	14.2	......	10.6	......	10.1	0.10
4	....	......	11.1	Trace	12.3	......	20	14.1	......	11.6	.33	10.1	......
5	....	......	11.0	0.03	12.0	......	21	16.5	0.32	11.0	......	11.1	.36
6	....	......	11.0	......	11.9	......	22	15.4	......	10.8	......	13.3	1.70
7	....	......	10.8	......	11.8	.01	23	14.8	......	10.8	......	13.1	.42
8	....	......	10.8	......	....	Trace	24	15.6	.25	10.7	......	10.5	Trace
9	....	......	15.3	2.35	....	......	25	14.9	.92	10.8	......	10.2	.11
10	....	0.12	10.8	.08	....	......	26	13.1	......	10.7	......	....	.12
11	....	.07	10.3	......	....	......	27	12.2	......	10.7	......	10.0	.01
12	....	.42	10.1	......	....	......	28	12.4	.21	....	......	10.3	.18
13	....	2.17	10.1	......	13.7	6.27	29	12.3	......	10.6	Trace	10.6	3.02
14	14.7	.15	10.2	.15	11.0	2.57	30	12.2	......	14.9	.99	10.2	.04
15	14.5	......	10.1	.04	10.4	.05	31	13.5	.53	....	......	10.0	.18
16	14.4	......	10.3	......	10.1	......							

a Determined by the electrical method at depth 3 to 6 inches.

EAST HARTFORD, CONN.

[Light wrappers and binders.]

Day.	May, 1895. Moisture. *a*	June, 1895. Moisture. *a*	July, 1895. Moisture. *a*	August, 1895. Moisture. *a*	Day.	May, 1895. Moisture. *a*	June, 1895 Moisture. *a*	July, 1895. Moisture. *a*	August, 1895. Moisture. *a*
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	....	16.6	15.9	13.2	17	13.9	15.8	13.8	15.3
2	....	17.5	14.9	12.3	18	13.2	15.6	13.5	17.3
3	....	16.2	15.4	11.4	19	16.1	15.4	13.1	16.2
4	....	14.8	17.3	10.9	20	16.0	15.2	12.9	15.3
5	....	15.2	16.4	10.7	21	15.7	15.1	12.9	14.8
6	....	16.4	15.6	10.9	22	15.3	14.9	12.9	14.2
7	....	16.8	15.2	16.8	23	15.0	14.7	13.2	13.9
8	16.4	15.2	15.4	14.4	24	15.2	14.0	12.2	13.6
9	17.9	15.3	15.6	13.0	25	16.0	13.4	11.9	13.4
10	17.7	16.2	15.7	13.0	26	19.4	13.0	12.3	13.2
11	17.1	16.6	15.9	13.4	27	16.8	14.9	14.3	13.1
12	16.6	15.7	15.7	13.8	28	15.9	16.3	13.4	13.1
13	15.8	15.3	15.0	13.4	29	15.7	17.3	11.0	13.0
14	15.4	14.9	15.5	12.8	30	....	16.7	16.2	12.9
15	14.9	15.0	14.9	12.2	31	....	....	14.2	12.9
16	16.6	15.6	14.4	13.3					

a At depth 0–12 inches.

EAST HARTFORD, CONN.

[Dark wrappers and binders.]

Day.	May, 1895.	June, 1895.	July, 1895.	August 1895.	Day.	May, 1895.	June, 1895.	July, 1895.	August, 1895.
	Moisture. *a*	Moisture. *a*	Moisture. *a*	Moisture. *a*		Moisture. *a*	Moisture. *a*	Moisture. *a*	Moisture. *a*
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
1	....	22.0	26.5	23.0	17	19.7	15.6	24.5	29.0
2	....	20.5	26.2	24.1	18	19.3	15.3	23.8	29.7
3	....	19.3	25.7	23.0	19	18.6	15.0	23.4	28.0
4	....	19.2	25.0	22.9	20	19.7	14.9	22.8	26.7
5	....	20.7	24.7	22.4	21	20.2	14.7	22.2	25.3
6	....	20.2	24.3	21.5	22	20.5	14.5	21.4	24.9
7	....	19.3	23.8	29.0	23	20.2	14.3	20.5	24.5
8	20.8	18.3	23.6	26.8	24	19.7	14.6	20.0	24.2
9	20.7	17.7	24.5	25.0	25	20.0	15.1	19.4	23.7
10	19.9	17.2	24.6	24.7	26	20.3	15.7	19.2	23.3
11	19.7	16.8	24.6	24.9	27	21.9	15.4	19.3	22.7
12	19.4	16.6	24.8	25.9	28	20.6	15.0	19.8	22.3
13	19.7	16.4	25.4	25.5	29	20.1	15.1	23.7	21.9
14	19.9	16.2	25.4	25.0	30	22.7	15.3	26.8	21.5
15	20.1	16.0	25.2	25.5	31	26.1	....	24.3	....
16	20.1	15.8	25.0	24.6					

a At depth 0–12 inches.

LITITZ, PA.

[Fillers.]

Day.	May, 1897. *a*		June, 1897. *a*		July, 1897. *a*		August, 1897. *a*	
	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1	25.3	....	17.5	....	11.2	....	32.0	....
2	34.0	1.20	24.3	0.06	11.3	0.21	23.0	....
3	33.7	.04	22.8	....	11.2	....	22.6	....
4	34.0	.73	22.4	.03	11.3	....	22.3	....
5	33.7	.03	36.1	2.25	11.2	....	24.3	0.59
6	33.1	....	34.0	....	11.2	....	23.8	.01
7	31.5	....	32.6	....	11.2	....	23.0	....
8	29.8	....	31.2	.03	11.2	....	22.3	....
9	29.4	....	33.4	.15	10.2	....	22.3	.01
10	28.6	....	36.5	....	10.2	....	22.6	.05
11	29.2	.22	30.0	....	9.6	....	25.3	.81
12	28.8	.16	29.6	.18	9.5	.28	24.3	....
13	36.1	1.30	28.4	....	29.2	1.90	22.8	....
14	33.7	.76	28.1	.03	25.8	.03	21.9	....
15	35.0	.28	27.0	....	22.5	....	21.3	....
16	33.4	....	26.3	.03	19.6	....	25.0	1.34
17	31.7	....	24.8	....	15.7	.04	23.4	....
18	29.6	....	24.8	.10	15.1	.11	22.4	....
19	29.4	....	22.1	....	28.4	.72	21.9	....
20	29.4	....	20.9	.09	31.3	....	21.7	.11
21	28.6	....	17.6	....	31.5	....	21.4	....
22	30.5	.42	13.4	....	31.0	....	21.2	.11
23	29.2	....	17.9	....	30.5	....	21.1	....
24	28.4	.27	15.0	....	23.2	....	31.0	1.79
25	32.0	.32	13.6	....	20.8	....	29.2	.10
26	30.7	....	13.3	.13	17.5	....	27.4	.01
27	28.2	....	11.9	....	22.6	.24	25.0	....
28	28.5	....	11.2	....	....	1.81	24.0	....
29	....	....	11.2	....	....	.30	22.6	....
30	....	....	11.2	....	....	....	21.0	....
31	26.4	.24	....	....	....	....	21.4	....

a Determined by the electrical method at depth 3 to 6 inches.

GERMANTOWN, OHIO.

Day.	May, 1897. *a*		June, 1897. *a*		July, 1897. *a*		August, 1897. *a*	
	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1			26.4				24.6	0.10
2					18.2		28.7	.62
3			24.7	0.19	18.3		29.0	
4			25.2				27.0	
5			24.4			Rain.	26.4	
6	37.4		23.2		23.4	1.10	25.8	
7	36.3				22.9		25.5	
8	33.5		31.9	.43	22.4		25.1	
9		0.60	30.0		21.6			
10	31.9		28.5					
11		.70	28.3			.20		
12	31.6				20.3			
13	29.6		30.8	.45				
14	29.6		30.6					
15	31.6	.08				.19		
16	29.9					.56		
17	28.5			.37		.25		
18	27.1				30.5			
19	25.0			1.02	29.0			
20					26.5			
21	32.4	.50			34.9			
22	33.4				27.7	.86		
23	33.6	.40			27.7			
24	37.4	.62	18.5		27.7	.21		
25	34.5		18.5		27.7	.80		
26	32.9		18.5		30.0			
27	31.9		18.4		28.4			
28	33.0		18.4		28.9			
29	31.3		18.3		26.1			
30	31.1		18.9		25.4			
31	27.0				25.2			

a Determined by the electrical method at depth 3 to 6 inches.

FORT MEADE, FLA.

Day.	May, 1897. *a*		June, 1897. *a*		July, 1897. *a*	
	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.
	Per ct.	*Inch.*	*Per ct.*	*Inch.*	*Per ct.*	*Inch.*
1	10.2	0.12			7.9	
2	10.3				7.5	0.28
3	8.3				10.5	1.32
4	7.8				8.9	
5	7.6				10.7	.41
6	7.3				9.3	.04
7	7.0		7.5	0.13	9.2	
8	7.1		7.4		9.2	.15
9	7.0		8.0	.55	10.7	.11
10	6.8		9.0		9.2	.07
11	6.8		7.9		10.5	.47
12	13.6	1.30	8.1		11.0	1.96
13	11.4	1.90	8.0		10.8	1.89
14	9.2	.30	10.8	.59	9.7	.14
15	11.0	1.05	8.6	.67	8.5	
16	9.7		9.0	.03	9.4	.08
17			8.8		8.1	
18			7.8		8.7	0.19
19	[illegible]		8.2	0.17	8.5	
20	8.0		8.6	.19	8.1	
21	7.9		8.8	.47	7.9	
22	7.9		8.5		9.1	.24
23	7.8		9.0		8.7	
24			8.7		8.4	
25			8.8	.41	10.6	.82
26			9.0		10.7	
27			8.9	.36	8.7	
28			8.7		8.8	
29			7.4		8.1	
30			7.9		8.8	.32
31					9.0	.18

a Determined by the electrical method at depth 3 to 6 inches.

Bright tobacco land.

OXFORD, N. C.

Day.	May, 1895. *a*	June, 1895. *a*	July, 1895. *a*	August, 1895. *a*	June, 1896. *a*		July, 1896. *a*	
	Moisture.	Moisture.	Moisture.	Moisture.	Moisture.	Rain.	Moisture.	Rain.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1		11.9	13.9	11.0			10.0	
2		11.4	14.3	10.7			9.6	
3		10.9	13.1	10.4			9.5	0.30
4		10.4	12.1	9.7			9.6	
5		10.1	11.0	9.2			10.4	
6		10.6	9.9	8.7			12.0	
7		10.2	8.9	8.6			15.3	.30
8		9.6	8.1	8.1			17.0	
9	18.3	8.8	7.4	6.8			17.6	.09
10	16.7	8.2	6.9	5.7			18.1	
11	15.4	8.6	6.6	5.1			18.2	
12	14.4	9.2	6.4	4.6	12.9		17.6	
13	13.5	8.7	6.0	4.4	12.8	0.60	16.5	
14	12.7	8.0	5.7	4.0	12.7		15.4	
15	12.2	7.4	5.5	3.7	12.6		14.4	
16	11.7	7.3	5.2	3.4	13.0		13.5	
17	11.3	7.3	5.0	6.7	13.2		13.1	.42
18	11.1	7.3	4.6	6.9	13.3		13.2	. 2
19	11.0	7.2	4.4	6.2	13.1		13.2	
20	13.4	6.8	4.2	5.6	11.6		12.8	.09
21	12.9	5.8	4.1	8.1	10.3		11.5	.12
22	12.7	4.7	4.2	7.4	10.3		10.2	.02
23	12.8	4.4	5.3	6.6	11.2	.55	9.0	
24	12.9	4.4	8.1	5.7	11.9	.20	8.5	
25	17.0	4.4	11.2	5.4	11.8		8.0	
26	16.4	4.3	12.1	5.0	11.7		7.8	
27	15.6	4.3	12.3	4.8	11.6		7.5	
28	14.8	4.3	11.7	4.5	11.2		7.2	
29	14.2	4.2	11.1	4.4	10.9		7.0	
30	13.3	4.2	10.6	4.3	10.7		6.8	
31	11.8			4.2			6.5	

Day.	August, 1896. *a*		May, 1897. *a*		June, 1897. *a*		July, 1897. *a*	
	Moisture.	Rain.	Moisture	Rain.	Moisture	Rain.	Moisture.	Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1	6.1		9.77		10.4		7.5	0.32
2	5.7	Trace.	10.07	0.56	9.8		7.4	.05
3	5.3		9.49	.20	9.0		7.3	
4	4.8		10.18		9.0	0.55	7.2	.25
5	4.9		10.18		9.8		7.2	
6	5.2		9.77	.10	9.0		7.0	
7	5.4		9.59		9.0		7.0	.08
8	5.6		9.01		9.0	.07	7.1	
9	5.7		9.01		9.0		7.1	.02
10	5.7		8.28		9.0		7.1	
11	12.9	1.50	8.86	.05	9.0		7.2	
12	12.1	1.12	10.10	.27	7.8		7.2	2.01
13	11.0		10.72	.52	7.9		8.9	
14	10.0		11.04	.85	7.4	.06	8.6	
15	9.0		10.52		7.4		8.9	
16	8.1		10.07		7.4		9.0	
17	7.3		9.77	.05	7.3		9.0	.52
18	6.8		9.50		7.2		10.4	
19	6.6		9.33		10.5	.55	10.6	.40
20	6.3				10.8	.80	10.7	.70
21	6.2	Trace.			10.4		10.8	.10
22	6.0				9.7		11.0	.06
23	5.9				9.0		9.9	
24	5.4	Trace.	9.01	.11	8.9		9.9	.20
25	5.0		9.01	.07	9.0		9.5	
26	4.6		9.01		7.8		9.4	.05
27	4.2		8.94	.02	7.9	.27	9.2	.03
28	4.1		8.86		7.8		9.1	.10
29	4.0		9.01		7.8		9.1	
30	4.1		8.66		7.6		9.5	
31	4.3		10.64	.85			11.0	

a At depth 0-12 inches.

Bright tobacco land.

WILSON, N. C.

Day.	June, 1897. *a* Moisture.	June, 1897. *a* Rain.	July, 1897. *a* Moisture.	July, 1897. *a* Rain.	August, 1897. *a* Moisture.	August, 1897. *a* Rain.	Day.	June, 1897. *a* Moisture.	June, 1897. *a* Rain.	July, 1897. *a* Moisture.	July, 1897. *a* Rain.	August, 1897. *a* Moisture.	August, 1897. *a* Rain.
	Per ct.	*Inch.*	*Per ct.*	*Inch.*	*Per ct.*	*Inch.*		*Per ct.*	*Inch.*	*Per ct.*	*Inch.*	*Per ct.*	*Inch.*
1	......	......	6.7	0.04	5.8	......	17	13.0	......	8.3	......	3.3	......
2	......	......	6.5	......	5.9	......	18	11.5	......	7.9	0.06	3.1	......
3	......	......	6.4	.55	5.8	......	19	11.2	0.26	7.6	......	3.0	......
4	8.5	......	7.0	......	5.6	......	20	10.6	.09	8.9	Rain.	3.0	0.16
5	9.3	0.32	6.9	......	5.5	......	21	9.6	......	8.8	1.40	2.9	......
6	9.5	.14	6.6	......	5.3	......	22	8.8	......	9.1	.38	5.8	1.62
7	9.5	......	6.3	.09	5.2	0.37	23	8.2	......	8.8	......	5.6	......
8	9.0	.01	6.1	.60	5.3	......	24	8.0	.22	8.2	......	5.4	.05
9	8.9	......	6.6	......	5.1	......	25	7.9	.20	7.8	.46	5.3	......
10	8.6	......	6.4	......	4.9	......	26	7.2	......	7.2	......	5.2	......
11	8.3	......	6.2	.01	4.8	......	27	7.1	......	7.1	.26	5.0	......
12	8.0	......	6.0	3.73	4.6	......	28	6.9	......	7.0	.11	5.0	......
13	7.8	......	11.3	......	4.5	......	29	6.9	.04	6.8	.04	4.8	......
14	7.4	......	10.6	......	4.1	......	30	6.8	.02	6.5	......	4.5	......
15	7.4	......	9.8	......	3.7	......	31	......	......	6.2	......	4.3	......
16	15.1	2.21	9.0	......	3.5	......							

a Determined by the electrical method at depth of 3 to 6 inches.

DANVILLE, VA.

Day.	July, 1895. *a* Moisture.	August, 1895. *a* Moisture.	Day.	July, 1895. *a* Moisture.	August, 1895. *a* Moisture.	Day.	July, 1895. *a* Moisture.	August, 1895. *a* Moisture.
	Per cent.	*Per cent.*		*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*
1	17.0	11.0	12	16.7	8.8	23	13.0	12.0
2	15.5	10.4	13	13.5	8.3	24	17.7	10.1
3	13.6	9.7	14	12.1	7.7	25	16.8	8.7
4	12.6	9.7	15	17.2	7.6	26	15.2	7.6
5	12.0	9.9	16	16.0	11.9	27	14.8	6.8
6	12.0	10.5	17	13.7	14.0	28	12.8	6.3
7	13.0	11.5	18	12.8	12.2	29	12.0	5.9
8	13.2	12.5	19	12.5	8.5	30	11.7	5.8
9	10.6	11.7	20	12.5	8.1	31	11.5	5.7
10	10.6	10.5	21	14.2	15.4			
11	16.8	9.7	22	13.5	14.2			

a At depth 0-12 inches.

HANOVER, VA.

Day.	June, 1895. *a* Moisture.	July, 1895. *a* Moisture.	August, 1895. *a* Moisture.	Day.	June, 1895. *a* Moisture.	July, 1895. *a* Moisture.	August, 1895. *a* Moisture.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	9.7	10.0	7.8	17	7.7	11.5	5.0
2	9.0	10.8	7.6	18	7.3	10.2	5.0
3	9.8	9.0	7.4	19	7.1	9.0	5.0
4	11.0	8.1	7.1	20	7.0	8.4	5.0
5	10.5	7.7	6.9	21	6.9	8.2	4.9
6	9.9	7.4	6.8	22	6.8	8.0	4.8
7	9.0	7.2	6.7	23	6.7	8.0	4.7
8	8.3	7.8	6.5	24	11.5	8.1	4.2
9	8.4	8.2	6.4	25	10.0	8.1	4.1
10	9.5	8.5	6.0	26	8.5	8.0	4.2
11	10.4	8.7	5.6	27	9.6	8.0	4.3
12	10.3	8.9	5.5	28	10.6	8.0	4.4
13	10.1	8.5	5.4	29	9.5	8.0	4.5
14	9.9	8.2	5.3	30	9.6	8.1	6.0
15	9.0	9.5	5.2	31	......	8.0	5.1
16	8.3	12.0	5.1				

a At depth 0-12 inches.

Burley tobacco land.

LEXINGTON, KY.

Day.	June, 1895. *a*	July, 1895. *a*	August, 1895. *a*	June, 1896. *a*		July, 1896. *a*		August, 1896. *a*	
	Moisture.	Moisture.	Moisture.	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1	25.6	28.2	26.6	26.0	1.00	23.5	....	25.3	0.42
2	24.7	27.5	25.4	26.7	....	23.1	....	25.0	1.47
3	24.4	26.3	24.3	27.2	1.35	23.2	....	24.1	....
4	24.2	25.2	24.2	27.6	....	23.8	0.49	24.0	....
5	24.1	24.4	24.1	27.7	....	23.9	....	24.0	....
6	23.9	24.7	27.7	27.8	.75	23.8	....	24.3	....
7	23.8	25.0	26.5	27.7	....	23.7	....	25.3	.57
8	23.6	25.6	25.5	27.5	.40	24.0	....	26.1	....
9	23.5	26.3	24.6	27.2	.60	27.9	1.59	25.8	....
10	23.3	26.4	24.2	26.8	....	27.8	....	24.5	....
11	23.1	26.4	23.9	26.7	....	27.5	.18	24.0	....
12	23.1	25.9	23.7	26.7	....	27.0	.07	22.6	....
13	23.3	25.6	23.3	26.7	.03	26.5	....	22.5	....
14	23.5	24.8	22.9	26.8	.01	26.0	....	22.8	....
15	23.8	24.1	22.7	26.9	....	26.0	.03	22.4	....
16	24.1	23.3	22.3	26.0	....	26.1	.62	22.1	.07
17	24.4	22.7	22.1	24.6	.03	26.1	....	21.8	....
18	24.1	22.1	21.9	23.8	....	25.6	....	21.8	....
19	23.9	22.0	21.7	23.3	....	25.5	....	22.2	....
20	24.4	22.8	21.2	23.1	....	28.4	1.25	22.9	....
21	26.3	25.0	20.6	23.0	....	29.8	2.30	23.5	.19
22	27.2	27.2	19.8	23.4	....	29.7	1.03	24.2	....
23	25.9	28.5	19.3	23.9	.63	29.0	1.02	24.6	.56
24	24.8	29.7	19.4	24.4	.05	28.5	.01	24.9	....
25	24.2	29.8	19.5	24.8	....	27.5	....	24.9	....
26	25.0	29.7	19.9	25.0	....	26.5	....	24.9	....
27	24.7	29.5	20.7	25.4	1.15	25.0	....	25.1	.04
28	23.6	27.9	21.5	25.6	.05	22.5	....	25.7	....
29	23.9	27.1	22.8	25.2	....	22.0	....	25.8	....
30	25.8	26.1	22.5	24.5	....	23.0	....	25.0	....
31	....	25.8	23.2	....	....	24.6	.56	23.8	....

Day.	May, 1897. *b*		June, 1897. *b*		July, 1897. *b*		August, 1897. *b*	
	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1	....	....	25.3	....	17.4	0.04	15.4	0.04
2	....	....	24.9	Trace.	17.1	.02	14.1	....
3	....	....	25.8	0.31	16.5	....	12.9	....
4	....	....	25.0	Trace.	16.6	....	12.0	....
5	....	....	24.7	....	16.3	.02	11.8	....
6	....	....	24.3	....	16.2	.13	10.3	....
7	35.6	....	23.7	.07	15.8	....	8.9	....
8	....	....	23.5	....	15.5	....	8.2	....
9	32.4	Trace.	22.9	....	15.2	....	7.7	.09
10	32.7	0.94	21.5	....	16.5	.33	7.5	.13
11	32.7	.34	21.6	....	16.7	.02	7.5	....
12	31.5	.43	20.7	....	16.7	.01	7.3	....
13	30.5	.01	19.5	....	16.3	.03	7.0	....
14	29.7	.04	18.4	....	16.0	....	6.8	....
15	29.5	....	17.0	....	15.5	....	6.9	.10
16	29.1	.05	16.0	....	18.2	.51	6.7	....
17	28.6	....	20.3	.93	17.8	.01	6.5	....
18	28.2	....	20.8	.51	17.4	....	6.4	....
19	28.0	....	19.5	....	16.9	Trace.	6.3	....
20	27.3	....	18.9	.18	16.6	.06	6.2	....
21	27.1	....	18.3	....	15.9	....	5.9	....
22	26.7	....	17.7	....	15.0	....	21.5	1.69
23	28.4	1.07	17.1	.07	13.5	.45	19.3	....
24	28.0	.28	21.0	2.04	15.2	.12	18.1	....
25	27.5	Trace.	20.4	.01	15.6	.46	18.4	.24
26	27.3	....	19.7	....	19.3	....	17.8	....
27	26.9	Trace.	19.1	Trace.	18.4	.01	16.9	....
28	26.9	.21	18.7	Trace.	17.9	....	16.1	....
29	26.7	Trace.	18.3	....	17.2	....	15.0	....
30	26.2	....	17.8	.10	16.7	.10	15.0	.33
31	25.8	....	....	....	16.1	....	14.9	....

a At depth 0–12 inches.
b Determined by the electrical method at depth 3 to 6 inches.

GREENDALE, KY.

Day.	June, 1895. *a*	July, 1895. *a*	August, 1895. *a*
	Moisture.	Moisture.	Moisture.
	Per cent.	*Per cent.*	*Per cent.*
1	21.4	23.8	26.0
2	22.7	24.7	25.0
3	24.2	23.3	24.4
4	25.6	22.1	24.1
5	26.4	21.1	24.7
6	26.3	20.2	26.2
7	25.6	19.3	25.9
8	24.8	18.8	25.0
9	24.2	17.9	24.8
10	23.8	17.4	24.3
11	23.6	16.5	22.4
12	23.8	16.1	21.5
13	25.5	15.9	22.8
14	25.8	16.0	22.2
15	24.1	18.3	20.8
16	22.5	20.6	22.1
17	21.1	19.3	21.9
18	21.1	17.0	21.2
19	22.0	15.5	21.1
20	22.8	16.0	21.0
21	22.5	17.0	20.9
22	21.6	18.3	20.9
23	22.0	19.6	20.9
24	24.7	20.9	21.0
25	24.7	24.2	21.2
26	19.0	26.2	21.1
27	13.6	26.9	21.0
28	12.6	26.7	20.8
29	13.6	26.6	20.7
30	15.6	25.9	20.5
31	....	25.2	21.5

a At depth 0-12 inches.

Export tobacco land.

HOPKINSVILLE, KY.

Day.	May, 1897. *a*		June, 1897. *a*		July, 1897. *a*		August, 1897. *a*	
	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.
	Per cent.	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*	*Per cent.*	*Inch.*
1	....	....	18.0	....	18.5	....	14.2	....
2	....	....	17.8	0.20	18.0	....	14.1	....
3	....	....	17.6	.15	17.2	....	13.9	....
4	....	....	17.5	....	17.0	....	13.8	....
5	....	....	17.2	....	18.1	0.23	14.2	0.18
6	....	....	16.9	....	18.2	.03	14.6	....
7	....	....	17.2	.15	18.0	....	14.8	....
8	....	....	17.6	....	18.8	....	14.8	.09
9	....	....	17.3	.02	17.7	.10	15.5	.09
10	....	....	17.2	....	17.2	.05	15.2	.65
11	....	....	17.2	....	16.8	.05	14.7	.40
12	....	....	17.2	....	16.1	....	14.6	....
13	....	....	17.5	....	15.9	....	13.8	....
14	....	....	17.3	....	15.7	....	13.7	....
15	24.3	....	17.2	.03	13.8	.45	13.6	....
16	21.3	....	18.0	.23	13.6	....	13.4	....
17	20.8	....	18.0	....	13.8	....	13.4	....
18	20.1	....	18.0	....	14.0	....	13.3	....
19	19.2	....	19.0	.30	14.2	.03	13.3	....
20	19.0	....	20.0	.67	14.7	.02	13.3	....
21	18.9	....	19.2	.40	14.6	.15	13.3	.02
22	18.0	....	19.0	....	14.8	....	13.2	.29
23	19.0	0.20	23.8	.45	14.7	....	13.2	....
24	18.5	....	25.4	.01	14.6	....	13.2	....
25	18.2	....	26.8	.02	14.8	.10	13.0	....
26	17.6	....	26.5	....	14.9	.31	12.9	....
27	17.5	.10	25.4	....	14.9	.05	12.8	....
28	17.4	....	20.1	....	14.8	....	....	....
29	18.0	.21	18.5	.15	14.8	....	....	....
30	18.5	....	19.0	.03	14.6	....	....	....
31	18.2	....	....	....	14.3	....	....	....

a Determined by the electrical method at depth 3 to 6 inches.

NEWSTEAD, KY.

Day.	June, 1895. *a*	July, 1895. *a*	August, 1895. *a*	Day.	June, 1895. *a*	July, 1895. *a*	August, 1895. *a*
	Moisture.	Moisture.	Moisture.		Moisture.	Moisture.	Moisture.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	20.0	22.2	20.9	17	15.7	16.0	13.3
2	19.8	21.6	20.7	18	15.9	16.0	13.2
3	19.5	20.2	20.0	19	15.9	14.8	13.3
4	19.6	18.5	19.3	20	15.1	14.5	16.0
5	20.0	17.6	18.4	21	14.2	14.0	15.2
6	20.5	18.3	17.6	22	14.5	13.8	14.7
7	19.9	20.0	17.0	23	15.2	14.8	14.0
8	19.3	21.6	16.5	24	15.2	18.2	13.3
9	17.9	21.9	16.1	25	14.7	20.5	12.9
10	17.1	21.5	16.7	26	14.9	20.3	12.8
11	17.1	20.5	16.4	27	15.9	20.2	12.8
12	17.4	20.2	15.8	28	15.3	19.6	13.0
13	16.5	19.2	15.2	29	15.3	19.2	13.8
14	16.5	18.8	15.0	30	17.4	20.8	15.0
15	17.0	17.8	14.5	31	....	21.6	14.5
16	16.3	17.1	13.8				

a At depth 0–12 inches.

Manufacturing tobacco land.

EASTHAM, VA.

Day.	June, 1895. *a*	July, 1895. *a*	August, 1895. *a*	Day.	June, 1895. *a*	July, 1895. *a*	August, 1895. *a*
	Moisture.	Moisture.	Moisture.		Moisture.	Moisture.	Moisture.
	Per cent.	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*
1	....	....	27.1	17	23.7	22.4	24.9
2	....	23.4	21.5	18	22.1	22.9	24.4
3	23.3	22.8	21.0	19	21.2	23.4	23.7
4	23.1	23.0	20.8	20	20.8	23.3	23.3
5	22.9	23.4	20.9	21	20.8	21.3	22.8
6	22.8	21.9	21.2	22	21.0	20.2	22.6
7	22.7	20.8	22.3	23	21.4	19.8	22.0
8	22.6	20.6	24.2	24	21.6	20.8	21.5
9	22.2	23.5	23.5	25	21.6	26.2	20.8
10	22.1	23.5	22.7	26	21.4	25.5	20.4
11	23.7	22.4	22.3	27	21.3	23.7	20.0
12	22.2	21.6	22.1	28	21.2	23.8	22.5
13	22.5	21.1	22.3	29	21.1	25.0	28.4
14	25.9	21.2	22.6	30	21.0	23.3	....
15	27.3	21.9	23.2	31	....	22.2	....
16	25.7	22.8	24.0				

a At depth 0–12 inches.

TABLES OF MECHANICAL ANALYSES OF SUBSOILS OF PRINCIPAL DISTRICTS.

The following tables give the mechanical analyses of the subsoils of the principal districts:

Cigar tobacco land.

NORTHERN DISTRICTS.

No. sample.	Locality.	Description and depth.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
	Massachusetts.		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1039	Hatfield	6–30 inches	0.21	1.48	0.00	0.00	2.50	28.11	55.78	10.71	0.63	0.92
1111	Whately	6–18 inches	.77	1.84	.00	.20	.30	8.91	69.98	14.35	.93	1.98
1173	Hatfield	8–30 inches	.59	2.71	.00	.00	.40	9.00	42.12	38.90	3.07	3.17
875	.....do	Subsoil	.66	2.15	.00	.00	.12	2.31	40.30	40.41	4.15	4.50
901	.....do	9–30 inches	.82	2.90	.00	.00	.21	2.13	38.11	45.09	4.76	5.98
	Average		.61	2.20	.00	.04	.71	10.09	49.26	30.89	2.71	3.31
	Connecticut.											
1066	Poquonock	12–36 inches	.41	.76	1.33	7.40	21.80	31.78	32.77	1.74	.45	.19
959	Windsor	11–35 inches	.58	1.30	.00	.07	.36	22.52	65.08	7.46	1.01	1.33
1305	Bloomfield	11–12 inches	.58	1.39	.40	1.18	4.68	39.87	45.11	3.82	.84	1.63
1277	South Windsor	10 inches	.84	2.13	.00	.16	.60	14.93	67.20	10.93	1.16	1.67
831	East Hartford	0–10 inches	.76	4.60	.82	5.39	19.51	24.47	28.34	11.88	1.20	2.41
842	.....do	10–30 inches	.46	2.08	1.05	5.03	18.31	25.83	32.11	11.31	1.15	2.51
1254	Poquonock	9–30 inches	.56	1.64	3.22	7.53	19.63	23.76	34.50	5.92	.78	2.53
729	East Hartford	.....do	.49	2.05	.09	.30	1.11	9.95	52.47	27.73	3.56	4.00
1303	Wethersfield	10–18 inches	2.18	6.85	2.39	2.32	3.26	10.51	51.66	12.94	3.03	4.65
	Average		.76	2.53	1.03	3.26	9.92	22.62	45.47	10.41	1.36	2.32
	New York.											
1357	Fulton	11–20 inches	.76	1.34	.94	1.33	2.67	14.84	71.28	5.41	.52	1.36
1279	Phœnix	18 inches	.91	1.71	.81	1.10	7.22	47.39	34.65	3.32	.95	2.58
1286	Butler	12–14 inches	1.51	5.40	2.60	4.57	18.01	37.71	16.44	6.44	2.43	5.21
1287	.....do	18–20 inches	.69	1.82	3.71	5.88	21.66	38.37	15.71	4.80	2.08	5.54
1281	South Granby	6 inches	1.21	2.26	.21	.29	.60	4.61	37.26	42.57	4.20	6.13
1353	Lysander	Subsoil	.93	2.63	2.20	4.17	14.90	23.60	21.21	19.16	3.48	8.05
1285	South Butler	9–10 inches	.84	1.89	1.73	2.05	4.41	17.67	39.56	18.08	3.77	10.08
1283	Fayetteville	6–18 inches	1.09	3.23	3.11	2.71	6.42	18.41	27.90	20.70	5.92	10.60
1355	Cato	9–18 inches	1.33	4.05	1.87	2.84	6.09	18.54	35.02	15.33	3.06	12.18
1289	Baldwinsville	Subsoil	1.32	3.83	2.21	3.03	8.17	23.58	26.16	15.12	4.51	12.55
	Average		1.06	2.82	1.94	2.80	9.02	24.47	32.52	15.09	3.09	7.43
	Pennsylvania.											
2568	Washington	Shaly limestone, 18–36 inches.	1.31	2.40	.13	2.31	21.77	8.92	24.77	21.57	4.41	11.83
2514	Washington, 2 miles east.	Shaly limestone, 12–30 inches.	2.36	3.01	2.55	3.03	3.90	12.20	29.33	22.53	6.96	12.27
2574	Columbia	River land, 12–30 inches.	2.26	2.64	.22	.30	1.66	9.18	52.32	13.82	4.50	12.68
2516	Washington	Shaly limestone, 12–30 inches.	1.87	2.69	.11	.18	1.37	1.60	42.83	28.43	4.96	16.03
2511	York, 4 miles south-east.	Phillite	2.36	5.40	.36	.33	.65	1.22	36.65	30.68	5.23	16.19
	Average		2.03	3.23	.67	1.23	5.87	6.62	37.18	23.41	5.21	13.80
2510	York, 9 miles east	Trenton limestone, 12–30 inches.	3.68	4.17	.57	.80	1.07	1.92	18.83	35.58	10.98	22.47
2570	Wrightsville	.....do	4.51	4.62	.88	.92	.96	1.30	17.72	36.82	7.14	23.87
2508	York, 3½ miles east	Trenton limestone, 12–24 inches.	2.40	3.52	1.06	.94	.67	1.15	12.35	43.64	8.79	25.23
2804	Lititz	Trenton limestone, subsoil.	2.85	4.83	1.41	1.38	1.55	4.98	15.54	30.52	5.27	31.96
1360	Marietta	Trenton limestone, 9–30 inches.	5.59	4.36	.12	.22	.27	.37	7.48	28.28	16.24	35.80
16	Lititz	.....do	2.63	5.30	.06	.40	.93	5.11	11.45	30.55	10.35	36.30
	Average		3.61	4.47	.68	.78	.91	2.47	13.89	34.23	9.79	29.27

Cigar tobacco land—Continued.

NORTHERN DISTRICTS—Continued.

No. sample.	Locality.	Description and depth.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
	Ohio.		P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
3090	Miamisburg	Glacial drift, 9–24 inches.	2.49	2.69	.15	.65	2.18	4.90	13.84	41.49	6.68	25.60
3111	Germantown	Glacial drift, 12–24 inches.	2.58	2.27	.03	.13	.48	.96	11.84	47.81	7.85	26.75
3120	.....do	.....do	3.96	3.06	.03	.20	.95	2.50	17.07	40.25	6.08	27.40
3121	.....do	Glacial drift, 24–36 inches.	3.16	2.68	1.36	2.07	5.38	11.80	18.71	20.86	5.05	30.35
	Average		3.05	2.67	.39	.76	2.25	5.04	15.36	37.60	6.41	27.52
	Wisconsin.											
1498	Newark	Limestone, 7–18 inches.	1.47	1.87	3.82	5.13	20.11	31.35	9.26	13.13	1.71	11.53
3259	Stoughton, 5½ miles east.	Oak opening, 9–30 inches.	2.98	1.94	.75	2.01	14.87	36.44	10.91	9.58	2.41	18.65
3249	Edgerton, 4 miles west.	Prairie, 12–36 inches	5.57	3.03	.18	.58	2.92	2.98	17.88	37.27	7.62	22.60
3245	Edgerton, 4 miles northwest.	Oak opening, 12–36 inches.	4.26	3.08	.06	.42	2.96	5.51	18.79	35.67	6.74	23.20
3253	Stoughton, 6 miles east.	Oak opening, 12–30 inches.	5.15	3.00	.02	.11	.41	.58	14.98	42.56	8.71	23.30
3257	Stoughton, 4 miles east.	Prairie, 9–33 inches.	6.06	4.24	.05	.09	.45	.84	17.30	39.35	8.46	23.75
3255	Stoughton, 4½ miles east.	Oak opening, 36 inches.	5.20	2.94	.52	.97	4.97	5.15	17.01	33.89	5.73	23.90
3247	Edgerton, 2 miles southwest.	Prairie, 12–36 inches	4.86	3.84	.15	.47	2.13	3.15	19.06	35.35	7.26	24.53
3251	Edgerton, ½ miles northwest.	Oak opening, 9–36 inches.	4.72	2.28	.38	1.06	.76	17.00	14.63	25.99	4.81	27.40
3254	Stoughton, 6 miles east.	Oak opening, 30–39 inches.	6.71	3.05	.00	.02	.18	.35	16.97	37.56	6.63	28.70
	Average		4.70	2.93	.59	1.09	4.98	10.34	15.68	31.04	6.01	22.76
	SOUTHERN DISTRICTS.											
	Florida.											
2827	Ocala	Light hammock, 0–9 inches.	0.35	1.16	(*a*)	1.59	15.63	62.87	15.70	1.25	0.48	0.61
2819	Fort Meade	Gray hammock, 0–30 inches.	1.06	2.50	0.80	3.81	13.77	50.10	24.41	.90	.55	.99
2821	.....do	Gray hammock, 20–36 inches.	1.03	2.16	.36	1.40	8.30	48.87	35.36	1.00	.52	1.17
2829	Ocala	Light hammock, 24–36 inches.	.30	.65	(*a*)	1.45	19.63	62.40	11.65	1.80	.62	1.26
2828	.....do	Light hammock, 9–24 inches.	.22	.75	(*a*)	1.80	18.25	65.37	10.07	1.20	.55	1.39
2823	Fort Meade	Mulatto hammock, 12–36 inches.	.47	1.43	.70	2.50	14.30	53.00	24.46	.62	.34	1.58
2820	.....do	Gray hammock, 0–20 inches.	1.39	2.88	.25	1.36	7.76	41.75	41.22	1.22	.70	1.58
2826	.....do	High pine land, 0–18 inches.	.47	1.60	.10	.65	4.58	47.88	40.90	.58	.23	1.68
2847	Silver Spring	Light hammock, 12–24 inches.	.19	.40	.62	5.57	28.66	52.7[illegible]	9.84	.38	.20	1.82
2822	Fort Meade	Mulatto hammock, 0–12 inches.	.62	1.53	.78	2.85	14.35	53.51	23.50	.65	.44	2.07
2837	Ocala	Mixed land, 0–12 inches.	.39	1.63	.09	4.07	32.31	44.72	11.10	2.55	.53	2.09
2845	.....do	Mixed land, soil	.31	1.34	.10	1.95	24.46	60.25	9.59	.42	.19	2.10
2838	.....do	Mixed land, 12–36 inches.	.06	.49	(*a*)	3.15	24.94	51.10	13.47	2.33	1.10	2.29
2830	Ocala, one-half mile south.	Light hammock, 0–12 inches.	.49	1.36	(*a*)	3.07	21.44	53.54	13.30	2.68	1.33	2.39
2841	Ocala, 2 miles south.	Mixed land, 24–36 inches.	.41	1.10	(*a*)	1.90	13.83	63.70	12.85	2.06	.94	2.48
2825	Fort Meade, 1½ miles south.	High pine land, 20–36 inches.	.48	2.22	.52	3.14	17.23	49.29	23.14	.62	.30	2.62
2824	.....do	High pine land, 0–20 inches.	1.54	3.02	.52	2.94	16.00	47.95	24.73	.86	.38	2.62
2852	Bartow	High pine land, 0–9 inches.	.81	3.37	.35	2.21	20.83	46.70	21.89	1.24	.41	2.83

a Trace.

Cigar tobacco land—Continued.

SOUTHERN DISTRICTS—Continued.

No. sample.	Locality.	Description and depth.	Moisture in air-dry sample.	Organic matter.	Gravel (2-1 mm.).	Coarse sand (1-0.5 mm.).	Medium sand (0.5-0.25 mm.).	Fine sand (0.25-0.1 mm.).	Very fine sand (0.1-0.05 mm.).	Silt (0.05-0.01 mm.).	Fine silt (0.01-0.005 mm.).	Clay (0.005-0.0001 mm.).
	Florida—Continued.		P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
2846	Ocala	Mixed land, sub-soil.	.24	.72	.32	2.42	27.55	57.44	6.84	.50	.24	3.00
2850	Bartow	High pine land, 0-9 inches.	.55	2.44	.17	2.31	19.74	45.32	25.71	.97	.38	3.05
2831	Ocala, one-half mile south.	Light hammock, 12-30 inches.	.32	.92	.28	3.30	22.29	55.29	10.64	2.62	1.64	3.06
2818	Fort Meade	Gray hammock, 20-36 inches.	1.06	3.06	.40	4.29	19.15	46.70	20.19	.78	.47	3.44
2853	Bartow	High pine land, 9-30 inches.	.54	1.24	.24	1.61	17.91	49.22	24.98	.78	.24	3.60
2817	Fort Meade	Gray hammock, 0-20 inches.	.94	2.13	.41	2.97	12.92	48.99	26.69	.74	.30	3.93
2839	Ocala, 2 miles south.	Mixed land, 0-12 inches.	.78	1.56	(*a*)	2.12	16.88	57.57	11.30	2.26	1.27	5.19
2851	Bartow	High pine land, 9-30 inches.	.36	1.09	.10	1.83	19.57	48.41	23.66	.65	.21	4.15
2840	Ocala, 2 miles south.	Mixed land, 12-24 inches.	.19	.72	(*a*)	1.95	13.15	62.53	12.35	1.81	.87	5.85
2842	Ocala, one-half mile east.	Mixed land, 0-9 inches.	1.11	3.46	(*a*)	3.50	32.95	34.15	10.64	2.96	.95	9.63
2843	Ocala, 1½ miles east.	Mixed land, 9-24 inches.	1.41	3.20	(*a*)	3.67	30.80	33.00	9.45	2.24	.87	14.66
	Average		.62	1.73	.26	2.60	18.94	51.53	18.95	1.33	.59	3.21
2894	Quincy	Lafayette, 0-12 inches.	.33	1.63	.13	1.61	9.48	56.71	20.82	3.75	.81	4.37
2897	do	do	.84	4.35	1.01	5.35	18.33	40.86	14.49	4.31	.99	7.95
2899	do	Lafayette, 0-9 inches.	.71	3.32	.45	2.10	19.25	47.37	15.28	4.99	.92	5.61
2901	do	Lafayette, soil	.43	1.41	1.11	10.33	33.07	37.18	9.14	3.53	.49	2.65
	Average		.58	2.68	.68	4.85	20.03	45.53	14.93	4.15	.80	5.15
2895	Quincy	Lafayette, 12-36 inches.	.53	4.00	.18	1.45	9.38	46.30	14.16	4.70	.88	18.16
2900	do	Lafayette, 9-30 inches.	1.31	5.89	.59	1.55	8.11	34.36	15.27	3.48	.77	29.15
2896	do	Lafayette, sub-soil	1.31	5.94	.51	1.24	6.06	33.41	13.58	2.79	1.74	34.15
2898	do	Lafayette, 12-20 inches.	1.55	6.92	.88	3.52	11.68	26.54	10.54	2.51	.88	35.73
	Average		1.18	5.69	.54	1.94	8.81	35.15	13.39	3.37	1.07	29.30
	Texas.											
2282	Willis	24 inches	.31	.55	.82	4.45	26.17	39.60	11.61	8.57	1.95	6.07
2284	do	20-24 inches	.14	.38	3.61	12.31	29.63	30.33	14.70	4.93	.84	2.65
2286	do	6-24 inches	.24	.44	.46	2.98	17.85	41.23	16.18	13.19	1.97	5.37
	Average		.23	.46	1.63	6.58	24.55	37.05	14.16	8.90	1.59	4.70
	California.											
2263	San Rafael	6-24 inches	1.27	3.91	2.94	5.49	19.44	27.33	12.85	13.37	2.18	10.77
	Cuba.											
308	Vuelta Abajo	Cigar tobacco	.54	3.83	1.70	6.20	9.40	18.20	48.85	8.03	.18	2.60
311	do	do	.46	2.46	1.00	6.60	15.10	26.75	39.05	4.46	1.44	3.15
310	do	do	.10	5.46	.13	.94	7.02	25.50	50.64	4.75	2.09	4.95
309	do	do	.55	2.68	3.45	2.80	4.50	18.70	55.80	5.11	1.04	5.34
307	do	do	.77	4.15	12.90	8.15	8.35	17.75	28.15	7.99	1.39	8.75
306	do	do	.99	4.20	5.20	3.03	5.30	23.15	36.05	8.82	3.97	9.35
	Average		.74	3.80	4.06	4.62	8.28	21.67	43.09	6.53	1.82	5.69
1959	Camajuani	Remedios (cigar) tobacco.	5.70	8.94	1.25	.41	.94	9.53	21.39	24.44	9.66	19.60
1958	do	do	3.84	8.62	3.21	.41	.49	3.85	14.77	17.80	7.90	34.85
1960	do	do	3.14	11.29	.65	.25	.30	3.20	14.05	17.90	11.81	37.10
1961	do	do	8.00	11.17	.15	.38	.36	1.47	9.69	24.80	8.09	37.71
	Average		5.17	10.01	1.31	.36	.52	4.51	14.97	21.24	9.37	32.32

a Trace.

Bright tobacco land.

VIRGINIA AND NORTH CAROLINA DISTRICTS.

No. sample.	Locality.	Description and depth.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
2032	Gills Station, Va., 2 miles south.	42 inches	0.40	2.09	0.60	8.08	20.66	26.52	25.38	8.24	5.54	2.48
741	Rockymount, N. C	Soil	.16	1.34	2.85	10.03	20.28	27.00	25.13	6.29	2.38	2.90
751	Lancaster, S. C	do	.26	2.52	13.68	18.34	23.45	25.73	12.90	7.85	1.80	3.12
746	Oxford, N. C	do	.18	1.50	2.56	7.89	25.63	23.65	18.70	13.51	3.16	3.33
745	Pitt County, N. C	do	.36	2.18	.00	.92	8.93	55.65	15.85	10.44	1.88	4.00
764	Lancaster, S. C	Subsoil	.00	3.17	6.41	17.48	29.66	17.18	7.14	12.86	2.05	4.05
760	Canton, N. C	do	.47	2.19	5.28	11.16	14.78	17.88	25.37	16.79	2.04	4.85
757	Cana, N. C	do	.91	2.58	3.76	3.22	9.55	19.86	27.77	20.60	6.18	4.87
754	Rockymount, N. C	do	.06	.87	2.97	8.96	17.26	25.14	25.40	11.71	2.73	4.91
744	Cana, N. C	Soil	.66	3.72	.00	2.47	9.14	19.60	37.28	17.32	4.08	5.08
2047	Boydton, Va., 9 miles east.	6–30 inches	.22	.88	3.79	24.93	26.99	15.71	12.10	7.78	3.01	5.18
1663	Danville, Va., near	do	2.62	.87	7.84	8.01	13.50	19.33	24.28	12.96	4.79	5.74
758	Pitt County, N. C	Subsoil	.81	2.30	.19	6.47	7.20	50.15	13.92	14.54	5.77	5.86
748	Weaverville, N. C	Soil	.70	3.64	4.38	6.22	9.42	12.73	28.01	23.25	4.91	5.94
1722	Kentuck, Va., one-half mile south.	4–15 inches	.97	2.85	1.45	5.93	11.91	23.28	26.06	16.01	5.23	6.24
750	Joy, N. C	Soil	1.10	5.13	5.16	7.85	8.17	13.65	26.90	20.95	4.51	6.27
747	Canton, N. C	do	1.00	4.52	4.22	8.35	10.60	14.70	32.42	14.23	3.02	6.67
742	Nelson, N. C	do	.34	1.92	1.02	3.36	9.78	23.62	31.17	17.68	4.46	6.90
1667	Kentuck, Va., 1 mile south.	6–15 inches	.40	2.73	.76	5.01	13.71	23.96	27.31	12.38	5.80	7.00
2049	Boydton, Va., 9 miles east.	6–12 inches	.34	2.11	1.90	7.97	21.90	22.17	21.15	9.95	5.66	7.42
749	Alexander, N. C	Soil	.46	3.05	3.15	8.50	15.19	15.86	24.67	18.45	4.25	7.90
2028	Gills Station, Va	18–30 inches	1.25	4.74	1.24	8.56	15.36	14.45	14.65	16.67	15.71	8.24
117	Oxford, N. C., 4 miles west.	12–16 inches	2.07	.15	.71	1.12	7.37	27.90	24.26	22.77	4.20	8.30
2030	Gills Station, Va, 2 miles east	4–16 inches	.38	1.41	1.19	7.63	16.77	21.83	13.20	16.22	13.74	8.59
761	Weaverville, N. C	Subsoil	.00	2.94	7.30	7.11	9.11	10.55	17.23	31.15	5.84	8.77
763	Joy, N. C	do	.00	.00	6.37	8.18	10.80	13.59	20.08	23.18	4.78	8.85
762	Alexander, N. C	do	.00	.00	3.93	7.89	10.87	11.14	15.52	28.08	7.94	8.91
1372	Danville, Va., near	6–20 inches	1.14	1.03	.14	.74	8.07	28.26	32.16	13.95	5.11	9.17
1329	do	6–18 inches	.44	1.98	4.96	6.30	10.55	17.10	29.03	14.99	5.87	9.25
2052	Boydton, Va., 6 miles east.	6–12 inches	.34	2.02	2.01	11.30	21.88	20.52	17.61	9.92	5.30	9.56
1605	Danville, Va., near	6–18 inches	.71	2.40	1.61	2.29	5.57	19.58	33.13	19.16	6.13	10.00
2031	Gills Station, Va., 2 miles south.	16–30 inches	.70	2.40	1.38	8.04	16.36	18.86	19.73	11.83	10.61	10.05
694	Danville, Va., 9 miles north.	4–30 inches	.38	1.74	.24	.76	5.53	27.35	32.73	15.12	5.55	10.43
2068	Lawrenceville, Va., 4 miles east.	6–18 inches	.42	1.66	.22	9.62	21.20	20.63	13.41	15.89	6.38	10.60
2066	Lawrenceville, Va., 5 miles northeast.	6–30 inches	.30	1.57	1.91	9.47	21.75	26.28	14.41	7.42	6.25	11.11
1751	Kentuck, Va., one-half mile south.	15–30 inches	10.21	6.00	.81	3.32	6.23	11.78	23.91	17.32	9.14	11.24
1668	Kentuck, Va., 1 mile south.	do	8.26	9.99	.16	.73	6.92	14.55	25.50	15.67	8.75	11.46
696	Danville, Va., 7 miles north.	4–12 inches	.72	4.60	.64	1.00	6.30	22.53	36.14	12.45	5.28	11.84
2045	Boydton, Va., 10½ miles east.	6–20 inches	.74	1.96	.83	8.70	16.96	20.25	20.92	11.58	5.08	12.87
2027	Gills Station, Va	6–18 inches	.56	2.24	1.66	8.55	18.34	20.05	19.73	11.24	5.16	13.20
753	Hyco, Va	Subsoil	.72	3.40	.00	.60	1.82	4.69	40.19	31.27	4.84	13.28
789	Danville, Va	6–18 inches	5.13	2.61	1.14	3.58	11.75	28.96	21.68	6.54	3.62	15.05
1833	Kentuck, Va	6–30 inches	.96	2.47	1.42	3.31	6.58	16.39	31.05	15.66	5.94	15.98
755	Nelson, N. C	Subsoil	.56	3.40	1.17	3.31	7.90	18.22	26.49	17.58	4.41	16.58
	Average		1.10	2.24	2.57	6.39	13.67	22.02	23.45	14.08	5.43	8.23

Manufacturing tobacco land.

VIRGINIA DISTRICT.

No. sample.	Locality.	Description and depth.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.5 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
	Virginia.		P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
649	Charlottesville, 2 miles north.	Gabbro, 8–24 inches	2.34	5.16	6.21	6.30	5.62	9.72	12.56	11.55	10.88	30.60
2064	Lawrenceville	Gneiss, subsoil	2.23	8.68	1.14	4.40	4.86	9.90	20.04	12.41	5.26	31.58
646	Charlottesville, 1 mile northeast.	Gabbro, 9–24 inches	5.65	7.29	.44	.88	.86	.61	4.94	23.89	21.90	34.15
651	Lynchburg	Gneiss, subsoil	3.94	6.99	1.66	2.87	8.96	18.06	12.77	6.89	2.26	35.06
1665	Danville, 1 mile north.	do	12.33	7.85	.45	.40	1.04	4.16	18.33	15.05	5.70	35.20
2060	Lawrenceville, 4 miles east.	Gneiss, 12–30 inches	2.46	7.41	3.84	5.53	7.09	8.04	16.85	5.49	4.44	39.25
650	Charlottesville, 1 mile west.	Gabbro, 8–16 inches	2.78	6.74	3.84	5.61	5.43	7.73	10.11	8.62	7.74	43.18
658	Forest	Gneiss, subsoil	8.97	6.68	1.27	1.64	4.77	7.45	7.47	9.20	8.48	44.70
647	Charlottesville, 2½ miles northeast.	Gabbro, subsoil	8.51	8.49	.06	.17	.19	2.18	5.88	14.83	14.82	44.96
1664	Danville, 3 miles north.	Gneiss, subsoil	7.80	10.50	.16	.13	.25	.91	2.39	24.78	7.89	45.00
2062	Lawrenceville, 4 miles east.	Gneiss, 12–30 inches	3.21	9.19	.66	1.48	3.82	10.40	18.26	4.43	3.60	45.16
652	Lynchburg, 3 miles south.	Gneiss, subsoil	3.44	5.63	.35	1.37	5.72	14.73	10.79	6.70	4.62	45.84
654	Lynchburg, 5 miles west.	do	4.01	7.40	.65	4.23	8.48	12.54	8.93	3.82	3.69	47.13
1997	Mossingford	do	2.88	8.82	1.36	2.07	3.85	6.97	11.31	9.88	5.30	47.33
653	Lynchburg, 4 miles south.	do	5.31	7.13	.28	.88	7.34	9.52	5.42	9.48	6.66	48.20
644	Charlottesville	Gabbro, 8–24 inches	9.55	7.67	.56	.44	.83	1.71	5.56	13.49	9.55	50.11
655	Bedford Springs	Gneiss, subsoil	5.64	8.46	.72	.87	2.05	5.51	7.32	9.91	6.54	52.18
2056	Boydton, 1 mile east	do	3.56	9.12	.04	.02	.06	.32	6.44	17.84	11.26	52.31
642	Charlottesville, one-half mile northeast.	Gabbro, 8–24 inches	7.28	6.48	.67	.99	1.36	2.55	5.50	13.76	9.82	52.46
659	Forest, one-half mile south.	Gneiss, subsoil	8.23	9.07	1.02	2.27	4.39	6.96	4.51	5.09	5.94	53.13
656	Bedford Springs, 1 mile north.	do	6.47	10.50	.16	.42	1.53	5.76	4.08	8.92	5.74	54.53
	Average		5.55	7.87	1.22	2.05	3.74	6.94	9.45	11.29	7.67	44.38

Burley tobacco land—Lower Silurian (Trenton and Hudson River Limestone).

KENTUCKY AND OHIO DISTRICTS.

No. sample.	Locality.	Description and depth.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.5 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
	Ohio.											
3091	Georgetown, 3 miles east.	12–36 inches	3.24	2.96	0.16	0.93	1.96	2.84	11.31	47.71	6.68	22.25
3087	Aberdeen, 4 miles west.	12–24 inches	3.28	3.67	.20	.37	.48	.80	17.41	33.06	7.78	34.63
3082	Georgetown, 1½ miles southeast.	9–24 inches	4.05	3.46	.02	.09	.13	.42	9.65	34.77	7.70	40.83
3089	Higginsport, 6 miles north.	9–30 inches	4.32	3.98	.01	.03	.10	.45	6.13	32.25	8.35	44.50
	Kentucky.											
3072	Germantown, 2½ miles west.	0–12 inches	2.04	3.83	.02	.58	1.06	1.18	10.12	56.27	9.58	15.58
1101	Mount Sterling	6–18 inches	2.36	3.05	1.52	1.80	1.48	2.40	10.07	42.97	13.39	18.25
1851	Winchester	do	2.48	6.15	.60	1.84	1.77	1.38	3.17	43.26	18.20	22.50
3073	Germantown, 2½ miles west.	12–30 inches	3.28	2.70	.18	.67	.82	.57	9.46	50.03	8.49	23.50
1853	Winchester	6–18 inches	2.38	4.60	1.59	2.71	2.03	1.36	2.74	44.61	14.39	24.75
2585	Lexington, 10 miles southeast.	6–24 inches	3.08	3.69	1.73	2.66	1.90	1.13	5.36	45.76	9.47	25.71
1991	Greendale	13–25 inches	2.22	4.68	.98	1.51	1.17	.55	2.80	50.55	7.97	27.30
2583	Donerail, 1 mile south.	10–24 inches	3.43	4.38	1.22	2.57	3.03	3.00	5.77	38.59	8.75	27.61

Burley tobacco land—Lower Silurian (Trenton and Hudson River Limestone)—Cont'd.

KENTUCKY AND OHIO DISTRICTS—Continued.

No. sample.	Locality.	Description and depth.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.)	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
	Kentucky—Cont'd.		*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
1927	Lexington, 8½ miles northeast.	Subsoil	2.55	4.51	.14	1.82	2.38	1.54	5.73	45.90	7.88	27.73
3077	Chatham	12–30 inches	2.54	2.99	.13	.89	1.26	1.35	6.10	47.89	10.36	27.77
2588	Lexington, 10 miles southeast.	12–24 inches	2.65	3.30	1.23	2.49	2.20	.97	5.28	43.31	10.18	28.45
2959	Mays Lick, 2 miles south.	.....do	4.55	2.78	.31	.98	1.10	1.03	11.22	43.46	6.14	28.53
1849	Winchester	6–18 inches	2.92	5.62	.73	1.43	1.41	1.22	2.23	38.53	16.31	30.20
2960	Mays Lick, 2 miles south.	24–36 inches	3.79	3.30	.33	.96	1.22	1.25	7.99	46.59	4.72	30.70
3070	Maysville, 4 miles west.	0–9 inches	5.66	7.40	.11	.19	.34	.61	13.01	31.41	10.19	31.25
2580	Donerail, one-fourth mile south.	12–24 inches	3.64	4.88	.70	2.54	2.60	1.83	4.31	36.97	7.69	34.36
287	Lexington, 6½ miles north.	7–24 inches	4.68	4.92	1.12	1.82	1.37	.89	4.34	34.40	10.58	35.24
2589	Lexington, 10 miles southeast.	24–36 inches	3.52	4.10	.93	2.35	2.07	1.12	4.92	36.03	8.11	35.53
3069	Germantown, one-half mile east.	12–30 inches	3.61	3.91	.27	.58	.94	1.16	4.75	38.60	9.27	38.37
2586	Lexington, 10 miles southeast.	24-36 inches	3.89	4.38	1.43	2.80	2.35	1.40	4.10	33.34	8.05	38.62
2957	Maysville, 9 miles south.	12–30 inches	5.51	4.22	.46	.80	.89	1.20	9.06	34.55	6.42	38.63
1702	Lexington	9–18 inches	.76	8.53	.00	.00	.24	.11	.97	38.70	11.20	38.92
3071	Maysville, 4 miles west.	.....do	4.76	4.82	.13	.20	.23	.44	10.44	30.12	7.98	40.17
2581	Donerail, one-fourth mile south.	24–36 inches	4.26	4.86	3.01	3.21	5.24	3.42	5.03	26.42	5.94	40.88
3071	Maysville, 4 miles west.	9–18 inches	3.23	5.02	.05	.13	.25	.53	10.21	29.22	9.94	42.70
3080	Augusta, 1 mile south.	0–12 inches	5.80	5.10	.05	.13	.25	.46	7.67	28.73	9.10	43.20
	Average		3.48	4.42	.64	1.63	1.44	1.22	7.04	39.77	9.36	31.62

Export tobacco land.

KENTUCKY AND TENNESSEE DISTRICTS.

No. sample.	Locality.	Description and depth.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.)	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
2611	Clarksville, Tenn., 9 miles southeast.	Subcarboniferous limestone, 9–18 inches.	1.32	2.83	0.62	0.87	1.15	1.62	6.65	66.68	6.42	12.14
2605	Clarksville, Tenn., 11 miles east.	Subcarboniferous limestone, 6–24 inches.	1.24	2.74	2.47	4.63	6.37	7.71	10.37	45.29	4.69	14.52
2606	.....do	Subcarboniferous limestone, 24-36 inches.	1.20	2.36	4.58	7.99	9.04	10.20	9.90	34.74	4.96	15.24
2612	Clarksville, Tenn., 9 miles southeast.	Subcarboniferous limestone, 18–27 inches.	1.33	3.57	.28	.64	.93	1.67	5.17	60.45	9.38	15.24
3158	Hopkinsville, Ky., 2 miles south.	Subcarboniferous limestone, 0–12 inches.	2.26	2.96	.00	.05	.15	1.06	9.94	63.14	5.56	15.75
3232	Henderson, Ky., 9 miles south.	Subcarboniferous limestone, 9–36 inches.	2.30	1.80	.34	.34	.30	.66	13.83	60.20	4.09	16.48
1105	Earlington, Ky.	Carboniferous sandstone, 16–18 inches.	1.78	2.91	.18	.65	.94	1.74	19.83	47.72	6.14	17.03
2619	Clarksville, Tenn., 6 miles east.	Subcarboniferous limestone, 9–18 inches.	1.28	3.06	.07	.14	.52	1.76	4.11	64.43	6.78	18.25
2638	Springfield, Tenn., 1¾ miles north.	Subcarboniferous limestone, 9–18 inches.	1.17	2.35	.28	.36	.45	1.69	10.97	56.22	7.16	18.97

Export tobacco land—Continued.

KENTUCKY AND TENNESSEE DISTRICTS—Continued.

Number.	Locality.	Description and depth.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.)	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.05 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
			P. ct.	Pc. t.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
3135	Woodburn, Ky., 1 mile north.	Subcarboniferous limestone, 0–12 inches.	2.38	2.42	.02	.13	.23	3.72	15.35	52.52	5.91	19.05
2923	Springfield, Tenn., 4 miles north.	Subcarboniferous limestone, 9-18 inches.	1.63	4.10	.00	.11	.15	.59	3.54	58.44	12.30	19.21
1720	Clarksville, Tenn., 5 miles northeast.	Subcarboniferous limestone, 6–30 inches.	.78	4.14	.00	.04	.13	.91	8.46	56.46	8.98	19.38
726	Adams Sta., Tenn	Subcarboniferous limestone, subsoil	1.63	3.08	.00	.05	.15	.74	2.04	61.85	10.45	20.20
3215	Farmington, Ky., 2½ miles northwest.	Lafayette or Columbia, 9-27 inches.	2.66	2.40	.00	.06	.16	.34	12.10	57.95	4.10	20.50
1099	Newstead, Ky	Subcarboniferous limestone, 6–18 inches.	2.10	3.06	.05	.18	.11	.34	5.13	63.28	5.19	20.55
1880	Clarksville, Tenn., 8 miles northeast.	Subcarboniferous limestone, 0–6 inches.	.84	4.82	.00	.00	.32	1.29	10.77	46.66	15.12	20.63
2645	Springfield, Tenn., 1½ miles north.	Subcarboniferous limestone, 9–18 inches.	1.53	2.31	.15	.59	.50	.96	9.33	55.27	7.79	20.92
2598	Clarksville, Tenn., 8 miles east.	Subcarboniferous limestone, 12–24 inches.	1.52	3.44	.14	.23	.40	1.40	7.21	57.29	6.87	21.18
2615	Clarksville, Tenn., 6 miles east.	Subcarboniferous limestone, 9–18 inches.	1.35	3.00	.36	.31	.70	2.62	4.00	59.33	7.00	21.20
2646	Springfield, Tenn., 1½ miles north.	Subcarboniferous limestone, 18–27 inches.	1.82	2.65	.71	.81	.60	1.09	8.86	52.55	8.24	22.15
2647	.....do	Subcarboniferous limestone, 27–36 inches.	1.81	2.56	1.21	1.20	.88	1.41	10.51	50.46	6.30	22.45
2599	Clarksville, Tenn., 8 miles east.	Subcarboniferous limestone, 24–36 inches.	1.35	2.48	.24	.35	.59	1.47	8.31	55.55	6.24	22.61
2609	Clarksville, Tenn., 9 miles southeast.	.....do	1.63	2.97	2.77	2.35	2.81	3.21	7.35	46.69	5.33	22.68
1719	Clarksville, Tenn., 6 miles east.	Subsoil	.94	4.92	.00	.25	.50	1.65	8.27	53.09	6.99	22.70
2620	.....do	Subcarboniferous limestone, 18–27 inches.	1.61	3.08	.51	.54	.43	1.53	7.76	56.91	5.67	22.77
2591	Clarksville, Tenn., 7 miles east.	Subcarboniferous limestone, 8–21 inches.	1.41	2.55	.01	.01	.08	.39	3.03	62.02	6.27	22.82
3225	Corydon, Ky., three-fourths mile southeast.	Carboniferous sandstone, 9–36 inches.	2.81	3.34	.00	.00	.02	.06	18.35	48.60	4.29	23.17
1379	Allen Springs, Ky.	Subcarboniferous limestone, subsoil.	1.67	3.31	.20	.46	.63	2.23	13.65	47.09	6.58	23.26
2592	Clarksville, Tenn., 7 miles east.	Subcarboniferous limestone, 24–36 inches.	1.49	2.39	.00	.01	.05	.26	3.81	60.97	6.76	23.31
1431	Bowling Green, Ky.	Subcarboniferous limestone, 6–18 inches.	1.75	2.99	.11	.25	.50	2.34	13.51	47.52	7.20	23.43
3217	Farmington, Ky., 2 miles west.	Lafayette on Columbia, 9–24 inches.	4.08	2.46	.00	.02	.14	.46	14.09	50.50	4.56	23.60
2630	Springfield, Tenn., 4½ miles north.	Subcarboniferous limestone, 18–27 inches.	1.72	4.27	.93	.47	.44	1.06	11.43	48.38	6.70	23.88
2633	Springfield, Tenn., 7 miles north.	Subcarboniferous limestone, 9–18 inches.	2.56	3.75	.30	.41	.38	.66	10.72	48.50	7.91	24.34
2608	Clarksville, Tenn., 9 miles southeast.	Subcarboniferous limestone, 6–24 inches.	1.59	3.08	1.10	1.34	1.42	2.17	7.00	51.26	6.42	24.43
3136	Woodburn, Ky., 1 mile north.	Subcarboniferous limestone, 12–24 inches.	4.02	1.80	.13	.35	.36	3.72	11.85	48.50	4.96	24.90

Export tobacco land—Continued.

KENTUCKY AND TENNESSEE DISTRICTS—Continued.

No sample.	Locality.	Description and depth.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–0.1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
3171	Hopkinsville, Ky., 9½ miles south.	Subcarboniferous limestone, 12–36 inches.	3.63	2.43	.01	.12	.16	.44	7.71	55.44	5.16	25.00
3197	Paducah, Ky., 15 miles south.	Lafayette or Columbia, 9–30 inches.	4.60	1.88	.00	.02	.08	.22	10.95	51.91	4.08	25.35
2601	Clarksville, Tenn., 11 miles east.	Subcarboniferous limestone, 9–18 inches.	1.60	2.68	.03	.09	.21	.85	5.93	55.45	6.46	25.67
2624	Springfield, Tenn., 4 miles north.	Subcarboniferous limestone, 18–27 inches.	1.70	3.18	.01	.07	.13	.52	4.51	53.77	9.41	26.06
2629	Springfield, Tenn., 4½ miles north.	Subcarboniferous limestone, 9–18 inches.	2.06	4.18	1.99	.81	.50	.98	7.87	47.10	6.75	26.12
3169	Hopkinsville, Ky., 5 miles south.	Subcarboniferous limestone, 12–36 inches.	3.88	2.88	.10	.41	.57	2.08	10.84	47.19	5.80	26.33
2602	Clarksville, Tenn., 11 miles east.	Subcarboniferous limestone, 18–27 inches.	2.33	2.64	.02	.14	.32	.60	5.91	55.08	5.89	26.85
3137	Woodburn, Ky., 1 mile north.	Subcarboniferous limestone, 24–36 inches.	3.34	2.48	.15	.35	.51	6.46	15.14	40.46	4.40	27.00
2636	Springfield, Tenn., 4 miles north.	Subcarboniferous limestone, 6–18 inches.	1.81	3.54	.88	.90	.99	2.49	13.64	41.91	5.76	27.03
3227	Corydon, Ky	Carboniferous sandstone, 9–24 inches.	3.64	2.60	.00	.00	.02	.07	12.37	52.46	3.62	27.05
3159	Hopkinsville, Ky., 2 miles south.	Subcarboniferous limestone, 12–36 inches.	4.56	2.80	.03	.10	.21	.91	8.72	52.10	4.42	27.15
3138	Woodburn, Ky., 1 mile north.	Subcarboniferous limestone, 36–72 inches.	2.72	3.10	.11	.16	.92	17.48	18.37	28.07	3.51	27.53
3209	Fancy Farm, Ky., 3½ miles north.	Lafayette or Columbia, 9–27 inches.	4.82	3.06	.03	.03	.06	.11	12.32	48.63	4.65	28.23
3128	Planol, Ky	Subcarboniferous limestone, 12–36 inches.	3.74	3.18	.08	.53	.44	.92	8.33	49.99	5.77	28.55
3134	Rich Pond, Ky., 1½ miles north.	.....do	4.48	3.21	.00	.11	.33	.67	8.36	47.74	4.86	30.38
2642	Springfield, Tenn.	Subcarboniferous limestone, 12–24 inches.	2.87	3.11	.00	.03	.04	.19	3.79	50.91	7.43	31.55
2594	Clarksville, Tenn., 5 miles east.	Subcarboniferous limestone, 9–18 inches.	2.48	3.16	.35	.22	.30	.86	6.23	48.08	5.32	31.77
3139	Woodburn, Ky., 1 mile north.	Subcarboniferous limestone, 72–96 inches.	3.86	3.42	.17	.87	.82	3.94	8.63	38.62	4.68	36.30
	Average		2.28	3.01	.41	.59	.74	1.97	9.37	52.10	6.36	22.88

BULLETIN No. 13. S. 15.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF SOILS.

A PRELIMINARY REPORT

ON

THE SOILS OF FLORIDA.

BY

MILTON WHITNEY,

Chief of Division of Soils.

WASHINGTON:

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1898.

LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS,
Washington, D. C., February 26, 1898.

SIR: I have the honor to transmit herewith a preliminary report upon investigations of the principal soil formations of Florida, and to recommend that it be published as Bulletin No. 13 of this Division.

Respectfully,

MILTON WHITNEY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

PLATES.

TEXT FIGURES.

A PRELIMINARY REPORT ON THE SOILS OF FLORIDA.

INTRODUCTION.

In January, 1897, a reconnoissance trip was taken over Florida in order to make a preliminary study of some of the important soils and soil conditions of the State.

The principal types of soils examined were the first, second, and third quality of high pine land; the pine flats or so-called "flat woods"; the light hammock, the gray or heavy hammock, the mixed land, the heavy marl hammock; the pineapple land; the Etonia scrub, the spruce-pine scrub; and the Lafayette formation.

The principal localities and interests examined were the truck areas around Gainesville, Ocala, Orlando, Grand Island, Bartow, and Fort Meade; the tobacco areas of the Lafayette or "red-land" formation at Quincy, as well as the new tobacco areas at Ocala, Bartow, and Fort Meade; the pineapple districts at Orlando, Winterhaven, and along the east coast from Fort Pierce to Palmbeach; also the extensive scrub lands at Altoona known as the Etonia scrub.

There is a very marked difference in the character of the native vegetation on the different types of soil in the State. The hammock land, considered the most valuable for general purposes, has a more or less heavy growth of white oak, live oak, water oak, bay, hickory, magnolia, and dogwood, so dense at times as to form a veritable jungle. The white oak is found only on the very best hammock lands, while the red oak and the long-leaf pine grow together on what is called the mixed lands. The high pine land and the pine flats, as the names imply, contain a monotonous growth of long-leaf or spruce pine, the character of the land having a great influence upon the forest growth.

There is, as a rule, a more or less marked difference in the appearance of the soils of these different types of land, but notwithstanding the very great difference in the character of the vegetation on the hammock and pine land soil no appreciable difference has yet been found either from a chemical analysis or from an examination of the physical texture of the soils.

A brief description of the principal types of soil and the characteristic vegetation will be given, then a discussion of the chemical composition, of the physical texture, and lastly the water content of these soils will be considered with reference to the marked difference in the agricultural value.

DESCRIPTION OF THE SOILS AND VEGETATION OF THE DIFFERENT FORMATIONS.

PINE LANDS.

There are four important grades of pine land in the State—the pine flats or flat woods, and the first, second, and third quality of high pine land.

The soils of the pine flats have not been particularly examined, as they need underdrainage in order to make them at all productive. Besides being an expensive operation, this is at times an exceedingly difficult one on account of the flatness of the country and the slight fall which can be obtained to carry off the surplus water. The growth on the pine flats consists of the long-leaf pine, palmetto and grasses. The woods are open and very irregular in density; the soils are generally wet, with standing water from 1 to 4 feet below the surface. But few attempts have been made to reclaim or cultivate these flat woods on any extensive scale.

The first quality of pine land occurs only in small areas. It has a dark, rich, light sandy soil, in which a stick can often be pushed with ease to a depth of 2 or 3 feet below the surface. It has a very dense growth of long-leaf pine, so dense in fact that the trees are small, and for this reason it is frequently called "sapling" land. Plate I shows the characteristic growth of this land.

The soil, though loose and open like a garden soil in excellent tilth, holds together well, and has the property of taking any impression when molded in the hand, as a good quality of molding sand does. On drying it is not inclined to fall apart to a loose, incoherent condition, and roads through it have generally a compact, hard surface, very easy for traveling. This soil is very similar to the hammock and is considered quite as valuable as the hammock land for general agricultural purposes. What is said later in relation to the moisture of hammock soil probably applies to this also.

The second quality of high pine land covers vast areas in the peninsula. It is a very light, rather coarse, sandy soil, less coherent than the hammock or first quality of pine land. Still the roads through it are good. The characteristic growth is the long-leaf pine. The trees are sparsely set and often of quite large size. There is very little undergrowth, and a wagon or carriage can be driven through the forest in almost any direction. There is generally a good growth of grass, and these lands are very extensively used for grazing. Plate II shows the characteristic growth of this land.

These second quality high pine lands form the principal truck areas at Gainesville, Orlando, Winterhaven, Grand Island, and Bartow. The country is generally rolling, with differences of elevation of from 25 to 50 feet. The whole elevation of the lake region, which is extensively used for truck growing, is from 100 to 200 feet above sea level. The

CHARACTERISTIC GROWTH OF FIRST QUALITY HIGH PINE LAND AT FORT MEADE.

soil is a coarse white or yellow sand, underlaid by a coarse, sandy subsoil. It looks like a barren sea sand or a coarse, sharp, building sand, but that it is very productive is shown by the large and vigorous growth of pines, the luxuriant growth of grass, the great quantity of truck crops which can be produced during the season, and the enormous growth of beggar weed which takes possession of the land after the crops are removed.

TRUCK GROWING.

These second quality high pine land soils seem particularly adapted to truck growing. The climate of the region is such that the crops can be grown during the winter and placed upon the Northern markets during the winter and early spring. The winter months constitute the dry season of this locality. A particularly valuable property of these soils is the evenness of the water supply which they maintain. The surface of the ground quickly dries after a rain, and for a depth of an inch or two it is soon as dry as dust. Immediately below this depth, however, the sand is always moist. Truck crops seldom suffer on these soils from drought. It is claimed that in one year a crop of tomatoes was secured with but 1 inch of rain from the planting to the harvesting of the crop. Certainly a dry period which would cause a most disastrous drought upon the soils at the North appears to have hardly any effect on the crops of these truck soils. Several weeks after a rain the soil immediately under the dry surface is so moist that it will hold together when molded in the hand.

Four per cent of water seems to be an abundant supply for these truck lands, and 6 per cent makes the soil quite wet. During the past season the water supply in the soil at Winterhaven, at a depth of 3 to 6 inches, has never fallen below 3 per cent, although there have been periods of fifteen or twenty days without rain.

No reason can be assigned for the peculiar property these soils possess which enables them to maintain such a uniform water content. The soils are comparatively high, and the wells throughout the area are comparatively deep. Standing water is found on the average about 15 or 20 feet below the surface of the ground. Nowhere in the Eastern States are there soils similar to these where such a uniform water supply can apparently be maintained regardless of the frequency or amount of the rainfall. There are, however, in the Northwest, in southern California, and in Texas, soils which have this same power of withstanding drought to an even more marked extent than these high pine land soils. On some of these western soils it is no unusual thing for crops to thrive for a period of five or six months without rain and without irrigation.

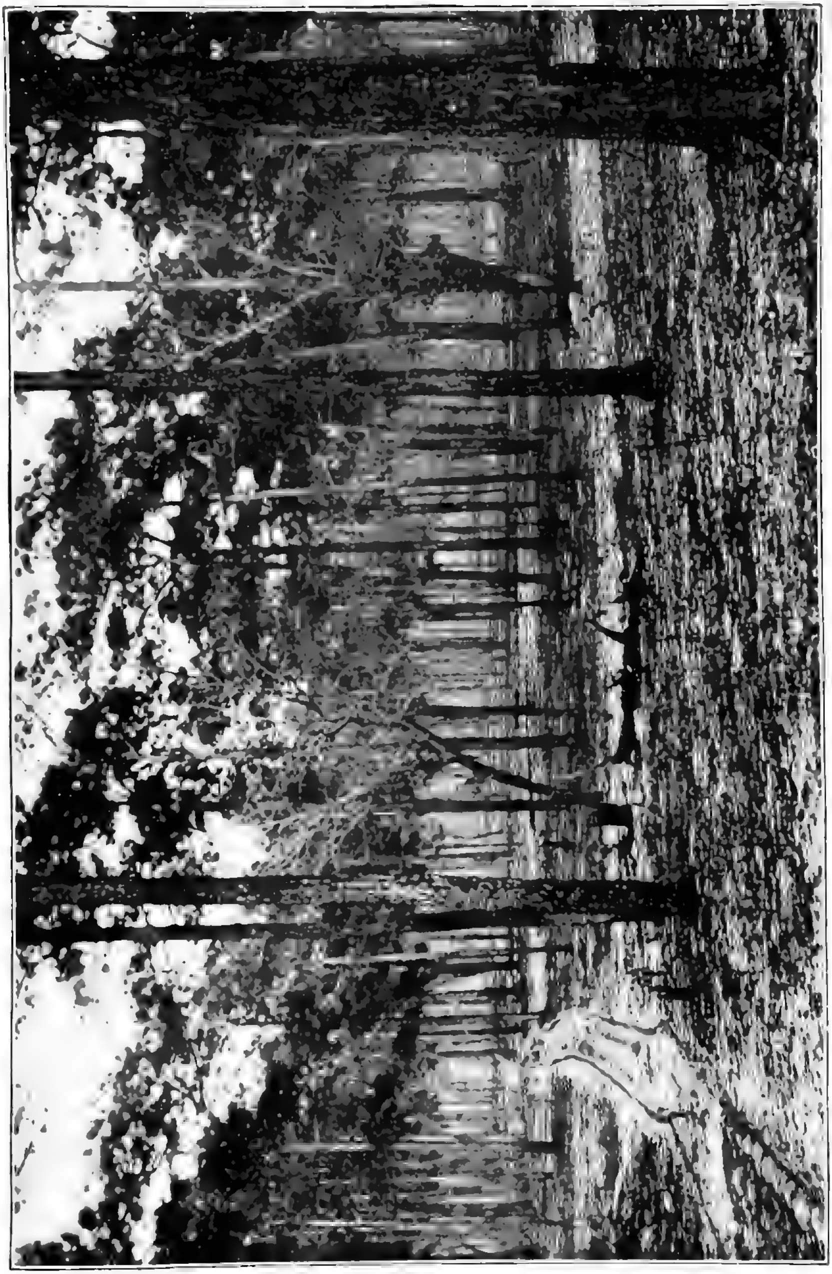
Nearly every important variety of truck crops is grown upon these soils. The crops are planted usually from September to January, and are harvested and shipped north from November to the middle of April. The best market of the year is naturally from about the middle of March to the middle of April, and during this period the shipping of truck northward is at its height.

It has been pointed out in other publications that the production and marketing of truck crops is a matter of very great expense. It is only by intensive methods of cultivation, the forcing of a large yield from a small area, and the ripening and marketing of the crop during the winter and early spring months, when there is no competition from the Northern soils, that the industry can be made to pay the high freight charges for hauling the tender and bulky products the great distance they have to go.

The combination of climate and soil offer, in the main, ideal conditions for truck farming. Unfortunately, however, there is danger of an occasional frost which injures or destroys the first planting of the truck crop and, besides entailing loss with the necessity of replanting, makes the crop late, which is a far more serious consideration owing to the competition which it is likely to meet from the more northern localities. On account of this danger from frost the favored localities in the lake region and the extreme south of Florida, which are in a large measure protected by the influence of the water, have exceptional value for this truck industry.

The truck interests in the State as a whole are so large and the system of cultivation is so intense, there is so much of value on a comparatively small area, and the frosts come so rarely, that it certainly seems as if adequate measures of protection could be provided to insure the crop against loss. There are methods of smudges and ways of creating currents of air, and of heating the air itself, which would probably be very efficient and quite economical if applied on a large scale in the truck fields. Two or three times a year there is danger from frosts or freezes when, if the air could be moderately agitated, if a covering of smoke could be thrown up from a field, or if the air itself could be directly heated and raised about 5 or 8 degrees in temperature, the crops could be saved. Without this protection the risks are undoubtedly very great.

The principal crops are handled in about the following way: Tomatoes are planted from September to January, and the crop is shipped north from November till the middle of April. Eggplants have about the same season of growth. Eggplants are extremely difficult to start, but they, together with green peppers, are considered the most profitable crops that are grown. Peppers last from two to three years, when the plant needs to be renewed. Strawberries are grown upon the lower and more moist lands near the lakes, the season being from the middle of January to the middle of May. Beans are planted from September to January, and are shipped from November to April. Onions are shipped from September to January; cauliflower seems to be rarely grown; cabbage is also but little grown upon these high pine lands, but very extensively produced upon the heavy hammocks and the clay



CHARACTERISTIC GROWTH OF SECOND QUALITY HIGH PINE LAND AT ALTOONA.

or marl hammocks. Peas are planted from September to March, and are shipped about six or eight weeks after planting. Sweet potatoes are planted from March to August, and mature throughout the year. Watermelons are planted from January to March, and are shipped from May to July. Irish potatoes are planted from September to the middle of January, and are shipped from the first of December to the middle of April. Celery is planted from September to January, and shipped from February to May.

As a rule, the truck soils are not occupied during the summer, and are allowed to grow up in crab-grass and beggar-weed, which produce an enormous growth beneficial to the soil and provide large cuttings of very nutritious hay. They are annual plants, and are well out of the way before the truck crops are put in. It is an advantage to have the soil thus protected during the summer time, and to have the organic matter added to the soil by the refuse is clearly an advantage to the plants.

The illustration, Plate II, is a characteristic view in second quality high pine land and, in contrast with Plate I, shows the marked difference in the character of the native vegetation on the first and second quality of land.

The third quality of high pine land consists of very loose and incoherent sand which on drying falls apart, so that the roads are exceedingly sandy and heavy for teams. The native growth of pine has little value. The soil is very poor and is not generally considered fit for cultivation.

HAMMOCK LANDS.

As already explained, the hammock lands are characterized by a native growth of hard-wood trees, principally of oak, hickory, magnolia, dogwood, and the cabbage palmetto. There are quite a number of grades of hammock land, distinguished by the kind and density of the growth, as well as by the character of the soil. There are light and heavy hammocks, so named from the density of the growth rather than from any appreciable difference in the character of the soil. The low, flat hammock, the high hammock, the heavy clay hammock, and the marl hammock, the various grades differing somewhat in the kind and relative proportion of the native trees.

As indicated by the name there is considerable difference in the texture of some of the hammock soils, but by far the largest area which has been studied consists of the light hammock and the heavy gray hammock, between which there is no apparent difference in texture. The soil and subsoil of these two hammocks consist of a moderately fine sand. The heavy hammocks are very dark colored, from the accumulation of organic matter from the dense growth which they have maintained in the past. This black soil is light and porous, and has the tilth of an excellent garden mold. It has a depth of from 1 to 3 feet.

These hammock lands are considered the most valuable in the State for general agricultural purposes. For special industries, however, especially for pineapples and some of the early truck crops, some of the other types of soil in the State have a higher value. The hammock soil at Fort Meade maintains about 8 per cent of water on the average, which is about twice as much as the high pine land truck soils at Winterhaven maintain. It seems strange, indeed, to a person familiar with the soils of the Northern and Western States, to see such a luxuriant growth of oak, hickory, and other hard wood trees on such light, sandy soil as this. The illustration, Plate III, gives some idea of the density of the growth on one of the heavy hammocks.

TOBACCO GROWING ON THE PENINSULA OF FLORIDA.

It was upon the heavy hammock land at Fort Meade that the tobacco industry received such an impetus about two years ago in the establishment of the Cuban colony at that place. Since then the industry has spread over all of the central portion of the peninsula, and has been developed upon all grades of hammock and pine lands.

The industry is so new that there is very little experience to draw from as yet in judging of what may be accomplished in the future. There is, however, much of promise in the results so far attained, and so much interest has lately been aroused in the subject of tobacco culture that a short statement of the conditions will not be out of the way.

It will be shown further along that, while this hammock soil maintains about twice as much moisture on the average as the second quality high pine land, the supply is not so uniform, and is subject to much greater variation, so that the crop is much more liable to drought. Tobacco is a plant which must be kept growing continuously. Any check is liable to change the character of the leaf, and for the cigar wrapper this is particularly undesirable. For the production of a fine, mild wrapper leaf it is necessary that the plant should receive no setback; for any check due to lack of moisture or of sufficient food material will tend to toughen the leaf, make it less elastic, and stronger when it is finally cured.

The filler leaf should be much stronger than the wrapper, as it forms the bulk of the cigar, and should determine the character. It is a mistake to suppose that equally good wrappers and fillers can be produced on the same plant. They should be treated differently from the very first. The filler should be raised upon a heavier, richer soil; and the plant produces a stronger, richer leaf if it is subjected to reasonable variations in the conditions of growth. The plants intended for filler leaves can be advantageously planted closer together, the soil can be manured much more heavily, the cultivation need not be so thorough, and a much heavier, closer, and stronger plant can be used than could be tolerated for the wrapper leaf.

It is the custom in this part of the State to make two main crops of

CHARACTERISTIC GROWTH OF HAMMOCK LAND AT FORT MEADE.

tobacco a year, namely, a spring crop and a fall crop. It is also customary to secure one or two sucker crops; that is, after the main crop is harvested a second crop is allowed to grow, and, as the plant has a full root development to nourish this sucker crop from the very start, the growth is rapid and usually rank and the leaves are strong and well fitted for filler purposes.

A plant intended for filler tobacco should be topped lower than one intended for wrapper leaves, so that the substance gathered by the roots will have fewer leaves to supply. The leaves will thus be stronger and more highly flavored. In the curing, also, the treatment of the wrapper and filler leaf is very different. The fermentation is carried much further with the filler, and petuning is practiced to still further increase the strength as well as to improve the aroma of the filler leaf.

It would unquestionably be well to specialize to a certain extent in the production of wrapper and filler leaves, and this is being done.

So far as it is safe to judge from a single season's experience, the high pine lands will grow a very pretty wrapper. The conditions are favorable for an even, rapid, and tender growth, as is apparent in the production of the truck crops. The conditions in these soils seem particularly well adapted to the production of a thin, elastic wrapper leaf. The best fillers, on the other hand, which have been produced so far have come from the hammock lands. At the same time the hammock soils have produced a very fine quality of wrapper leaf.

In order to secure the crop against injury from drought a very thorough system of irrigation is being practiced on the hammock lands. It is claimed that the crop matures in from forty-five to fifty days under judicious irrigation, against sixty to seventy days without irrigation. It is also claimed that it makes finer wrapper leaf.

The irrigation outfit consists of an engine placed near a watercourse, with a capacity of about 1 horsepower per acre and 1-inch or 1½-inch iron pipe laid near the surface of the ground for mains and laterals, the laterals being about 100 feet apart, with hydrants every 50 feet. Tanks are frequently used, but it is considered preferable now to pump directly into the mains so as to insure sufficient pressure. Nozzles are used which give an even spray, and which are moved from hydrant to hydrant by an attendant as the work progresses. Such an irrigation plant for a field of 20 acres or over costs from $100 to $150 per acre. Where the hydrants are not sufficiently close to cover the ground with spray a hose is used with a movable spray to water the space between the laterals. Plate IV shows the method of irrigation as practiced at Fort Meade.

Very recently the method of shading, which has been used with great success in the pineapple fields, has been adopted in connection with the tobacco. During the past season some very fine wrapper leaf was produced under the half shade at various places in the State. This method consists of erecting supports at convenient distances to carry a lattice formed of 3-inch strips placed 3 inches apart so that never more than half of the direct sun's rays reach the plant. This unquestionably maintains a more uniform condition of soil moisture and of relative humidity of air than is maintained in the open field. It insures a more continuous growth with less drain upon the plant during the heat of the day, and much more uniform conditions of growth at all times. These shades cost from $400 to $500 per acre. In some instances they have been completely covered with plant-bed muslin, so that the plants are never exposed to the intense rays of the sun.

It must not be forgotten that the tobacco plant when cut in the field is but the raw material out of which the finished product is to be made and with few of the properties of the finished leaf. Judgment must be exercised in setting out the plants, in the method of cultivation, in the matter of topping, and in the time of cutting. All of these are likely to have an important influence upon the plant grown upon any soil, but beyond this the barn curing, the fermentation, and the bale sweat must all be managed with the greatest care and judgment in order to bring out the fine qualities of the leaf. Each of these three processes is probably a distinct kind of fermentation, of the exact nature of which we have little certain knowledge. We know that it is necessary to maintain certain conditions in order that the leaf shall be in the proper condition for the changes which have to take place, although we do not know what these changes are nor the exact conditions which control them.

Even after the fermentation is apparently finished and the leaf put into the bale it should be allowed to remain undisturbed for at least two years in order to mellow with age and lose the harsh characteristics it still has when it comes out of the bulk. This is a matter of very great importance and one which can not be dwelt upon too strongly. The Florida grower has been too anxious to secure recognition for the crop, and has been compelled from lack of capital to sell his product immediately after it has been put into the bale. For this reason much of the tobacco has been made up into cigars without undergoing the bale sweat and, while much of the tobacco has given promise of good qualities, the full value of these has not been brought out for lack of age. This has done much harm to the tobacco industry of the State.

ETONIA SCRUB LANDS.

The great Etonia scrub formation was examined at Altoona. It is an impressive sight to stand at the border line between the scrub and the high pine land and notice the difference in the character of the vegetation. The high pine land is open, the trees are large and vigorous, and the ground is covered with a crop of grass which gives very good grazing for cattle. The vegetation is quick and generous and the most tender garden plants will grow luxuriantly if properly attended

METHOD OF IRRIGATING TOBACCO LAND AT FORT MEADE.

SHOWING THE CONTACT OF THE SCRUB WITH THE HIGH PINE LAND AT ALTOONA.

to. These conditions stop abruptly at the edge of the scrub. The boundary between the high pine land and the scrub can be located without trouble within a few feet. Plate V shows the marked contrast between the vegetation of the scrub and the high pine lands, and shows also how abrupt the transition is from one kind of vegetation to the other.

In the scrub there is a dense growth of scrub oaks and low bushes and plants, all having thick leaves protected to the utmost from loss of water by evaporation by the property that desert plants have of turning the leaves up edgeways to the sun to expose as little surface as possible to the direct rays. No grass is found, and only the most hardy desert plants grow. When pines grow it is the dwarf spruce pine and not the long-leaf pine, while on the other hand the spruce pine is not found across the border in the high pine lands proper.

The full-grown scrub vegetation reaches about the height of a man's head, as can be seen in the illustration, Plate VI. This scrub growth stretches out at this place in an unbroken line for 10 or 15 miles to the northward, and the whole country presents a most desolate appearance. The country is generally rolling in both the high pine land and scrub. There are lakes at which the scrub and the high pine vegetation meet at the water's edge. There is no indication from the topography of the country of any difference in the climate over the two soils. Very few attempts are known to have been made to cultivate the scrub lands. A few efforts to grow truck and oranges are known to have been failures. It is generally believed that the scrub is colder at night and that frosts are liable to occur over these areas when they do not occur over the high pine land. There is no apparent reason for this, however, in the topography of the country. There are differences in elevation in the scrub, in quite short distances, of 25 feet or more, over which the same growth extends in an unbroken line following the contours of the surface. The same character of growth extends down to the lake borders in what is almost a muck soil.

It will be shown later that there is no apparent reason, from the chemical or physical examination, to account for this difference in the native growth on the scrub as compared with the high pine land or the hammock and, so far as our investigations show, there is no difference in the soil. The only explanation for the difference in the character of the vegetation is that it is accidental and that the one kind of crop or the other received a start and simply spread, the two kinds of vegetation not being capable of growing together. As a matter of fact, however, in comparing the scrub with the high pine land the conditions in the scrub appear more natural than those in the high pine land. In such sandy soils as these the wonder is that tender vegetables can be grown at all, and that such a large and generous growth of pines and grass is naturally produced.

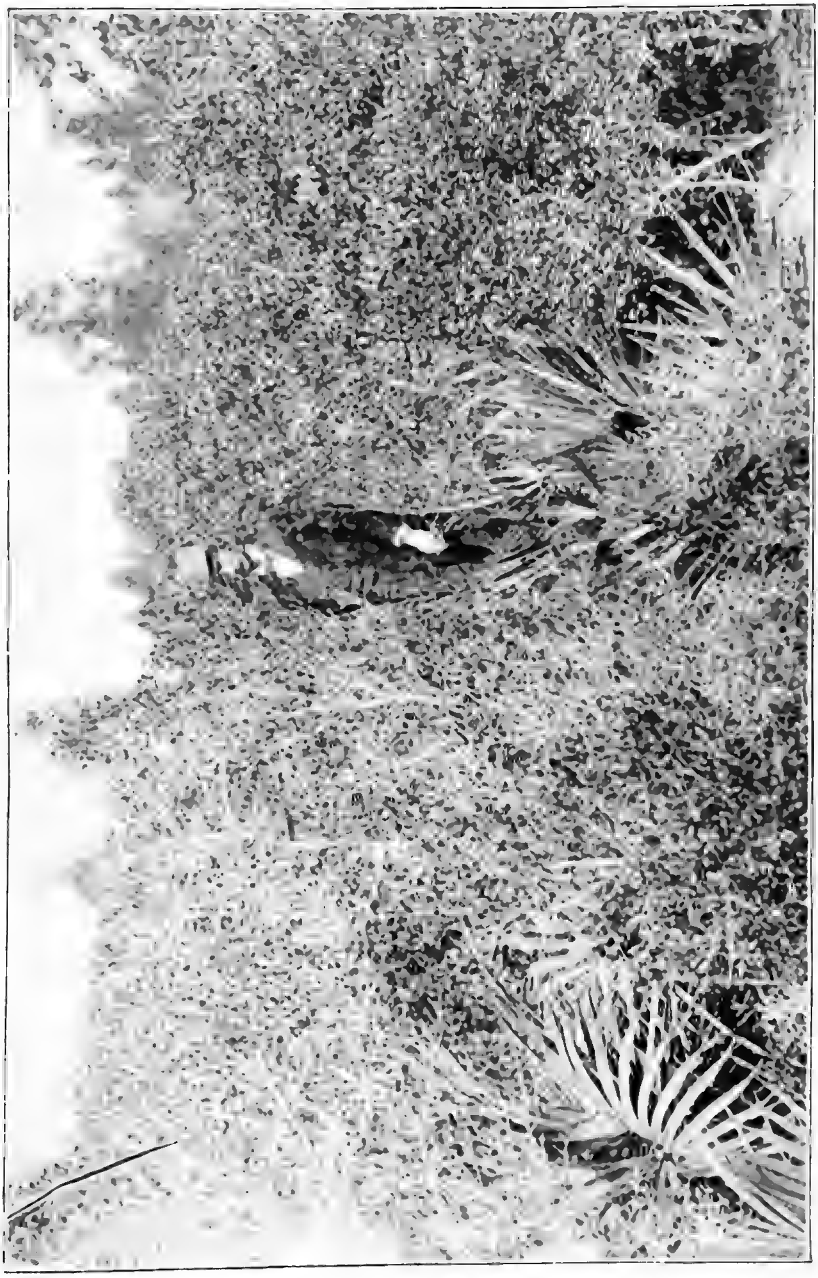
PINEAPPLE LAND.

Pineapples are grown very extensively on the high pine land at Orlando, Winterhaven, and at many other places in the center of the peninsula, but along the east coast from Fort Pierce down to Lake Worth there is a narrow strip of country devoted almost entirely to the pineapple industry. The pineapple lands comprise here a narrow strip, hardly more than an eighth or a fourth of a mile wide with the Indian River or the ocean on one side and the pine flats on the other, stretching out into the great savannas or everglades. The ridge has an average elevation of perhaps 15 or 20 feet. The growth is mainly scrub oak, spruce pine, and palmetto. Much of it is quite dense and the character of the growth makes it quite expensive to clear the land. The soil is a coarse sand, almost pure white and to all appearance as free from any trace of plant food as the cleanest glass sand. The subsoil is either a coarse white or yellow sand. The yellow sand is generally preferred, as it is considered rather stronger than the white. Nothing would seem more unpromising to a Northern farmer than the white sand thrown out from a ditch or exposed in a railroad cut extending through these pineapple soils, upon which the pineapple industry is so profitable and the returns are so sure that the growers can not only afford enormous applications of fertilizers, but expend from $400 to $500 an acre in irrigation or in covering the fields with open lattice sheds.

Until within the last year or two there was a lack of transportation facilities in this section. Owing to this, no truck crops or oranges had been grown except for family use. It is considered that the soils are too dry for trucking without excessive fertilization and watering, which could probably not be economically done. At Jensen and at Eden the country along the railroad looks like a continuous field of pineapples.

This land presents some very interesting problems to the student of the soil, as it appears to be lacking in every requisite of food and to have the physical conditions most unsuited to agricultural purposes. Having said so much, it may not be out of place to give an idea of the relative value of these lands for this special crop. This may be gathered from the following statement of the cost of starting a pineapple plantation at the present time at West Palmbeach.

The land costs uncleared from $50 to $100 an acre, or, if it is on the lake front, as much as $200 per acre. Clearing the land will cost from $75 to $100 per acre. It will require from 10,000 to 12,000 pineapple slips to set the acre, 18 by 18, or 20 by 20 inches between the plants. The common Red Spanish variety costs $5 per thousand, or $60 per acre. The fancy kinds of pineapple which are being set out now cost from $10 to $25 per hundred. Setting out the slips costs about $20 per acre. The slips are usually set out in July or August, and bear the first crop in a year from the following April, that is, in about twenty



CHARACTERISTIC GROWTH OF ETONIA SCRUB AT ALTOONA.

or twenty-two months from the time of setting out. One and a half to 2 tons of fertilizers are used per acre, applied in portions two or three times during the season. The more fertilizer used the more the crop is benefited. The crop responds generously to each application. Cotton seed, cotton-seed hulls, tobacco stems, and sulphate of potash are commonly used and cost from $40 to $60 per acre. Irrigation has been tried on rather an extensive scale and latterly shading has come into considerable use. The shading costs from $450 to $500 per acre, depending upon the distance from the sawmills. Only the finest varieties of pineapples, however, are shaded at present.

There is no more striking example of the adaptation of special soil conditions to particular crops than is afforded here, and the utilizing of conditions which could not possibly have been used for general agricultural purposes. If the whole country were looked over it would be hard to find a less promising soil than this, which, however, through a peculiar adaptation to a certain kind of plant has, when cleared and planted, a value ranging from $500 to $2,500 per acre and even more.

The months of March, April, and May constitute the dry season for that locality, and the two latter months are important in the pineapple industry, as that is the time when the apple is forming. Serious damage has often been done at this season by severe droughts, and to provide against this injury irrigation has been employed to quite a considerable extent. The usual method of irrigation is to produce a fine overhead spray with standpipes 3 or 4 feet high at intervals of from 15 or 20 feet each way. This method has not been altogether satisfactory, however, and lately the method of shading has come into considerable use. The roof of the open shed consists of 3-inch strips nailed to light frame work, the strips being 3 inches apart, so that less than one-half as much sunlight falls upon the plants or the surface of the ground as would be received if the shed were not there. This tends to retard evaporation from the soil and from the plant. It is also very efficient in protecting the plants against frosts, and it is used for this purpose extensively in the northern part of the pineapple area.

LAFAYETTE FORMATION OF WESTERN FLORIDA.

The Lafayette formation in western Florida is a continuation southward of the "red lands" of Wedgefield and Aiken, South Carolina, and of Georgia. It constitutes the oldest tobacco area of the State, where a fine quality of tobacco was grown many years ago and where the industry was first taken up again in the recent developments in the State. The tobacco industry was revived at Quincy about ten years ago in the introduction of cigar tobacco.

The soil of this locality is a fine, light, sandy loam, resting upon what appears to be a strong clay subsoil of considerable depth. The loam is generally from 6 to 18 inches deep, but the red clay is frequently exposed in road cuts and washed places in the fields. The country is rolling and covered with a native vegetation of hard wood trees.

It will be seen from the table of mechanical analyses that the loam overlying the red-clay subsoil contains about 5 per cent of clay. It corresponds closely with the tobacco soils of the Connecticut Valley and the early truck soils of the Atlantic coast States. It is advisable to have a depth of at least 12 or 18 inches of this loam over the clay for the production of a fine grade of wrapper leaf.

It will be seen from the table of mechanical analyses that the red-clay subsoil of these lands contains upward of 30 per cent of clay, fully as much as the heavy limestone soils of Pennsylvania and Ohio. There is, however, this peculiarity in this "red-land" formation as it occurs here and in South Carolina—that is, that it maintains only about 8 or 10 per cent of water, while soils having the same percentage of clay in Pennsylvania and Ohio on which a similar leaf is produced contain as much as from 18 to 22 per cent of water. A few records were obtained of the water content of the soil at Quincy and it was found to maintain about 8 per cent of water on the average to a depth of 24 inches. Strangely enough this is about the same percentage as is maintained by the hammock soil at Fort Meade, although the soils are so very different in their texture and general appearance. It is curious that the light sandy soils of the hammock land maintain so much water as this, and it is likewise singular that so little water is maintained on the average by these Lafayette clays which have so much real clay in their composition. Very little difference is shown to exist, therefore, between the tobacco soil of Quincy and the hammock soil at Fort Meade in regard to the water content or, as will be shown presently, in the soluble salt content of the lands. The statements in regard to the tobacco industry at Fort Meade apply equally to this section.

COMPARISON OF THE PRINCIPAL TYPES OF FLORIDA SOIL.

TEXTURE OF THE SOILS.

It will be seen from the brief description which has been given of the principal types examined that there is a marked difference in the character of the growth and in the agricultural value of the lands. The object of the present investigation has been to see if there is any reason to explain these differences. The problem was to discover, if possible, why the hammock land maintains a growth of oak, hickory, dogwood, and other hard-wood trees, often so overgrown with a luxuriant growth of bushes and vines as to make an impenetrable jungle. The pine lands, on the other hand, have no hard-wood trees except occasional scrub oaks, but support a vigorous growth of pine trees, with a luxuriant crop of grass and but scant undergrowth. The Lafayette formation has a characteristic hard wood growth. It has a subsoil containing far more clay than any other formation in Florida, and yet it has about the same agricultural value as the hammock soil at Fort Meade. The scrub land has a characteristic growth of scrub oaks and dwarf bushes, two peculiar species of palmetto, and the spruce pine.

The following tables give the mean texture as determined from the mechanical analyses of a number of samples of soil and subsoil from the various formations in the State, the detailed analyses upon which these are based being given at the end of this bulletin:

Summary of the mechanical analyses of Florida lands.

SOILS.

Number of samples.	Kind of land.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1-0.5 mm.).	Medium sand (0.5-0.25 mm.).	Fine sand (0.25-0.1 mm.).	Very fine sand (0.1-0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
		Per ct.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
2	Spruce pine scrub	1.06	0.65	12.36	41.42	41.18	2.40	0.16	0.06	0.35
4	Pineapple land	1.21	.23	3.02	61.11	33.76	.54	.22	.06	.50
4	Etonia scrub	1.24	.23	3.34	27.43	58.60	7.60	.55	.20	.87
12	High pine land	1.82	1.46	5.78	23.89	45.11	18.42	.96	.38	1.56
5	Gray hammock	1.84	.36	3.29	19.75	52.17	19.08	.66	.50	1.68
4	Light hammock	1.38	Trace.	3.63	28.85	51.37	10.34	1.38	.62	1.70
4	Rich, heavy hammock	2.68	.82	2.48	19.60	44.15	19.07	3.35	1.19	4.48
4	Mixed land	2.00	.05	2.91	26.65	49.17	10.66	2.05	.74	4.75
4	Lafayette	2.68	.68	4.85	20.03	45.53	14.93	4.15	.80	5.15

SUBSOILS.

Number of samples.	Kind of land.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1-0.5 mm.).	Medium sand (0.5-0.25 mm.).	Fine sand (0.25-0.1 mm.).	Very fine sand (0.1-0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.).
1	Spruce pine land	0.45	0.66	9.07	32.58	52.13	3.26	0.23	0.18	0.51
5	Pineapple land	.31	.06	3.08	57.50	37.78	.59	.07	.13	.52
4	Gray hammock	1.61	.27	3.79	22.99	53.53	14.54	.48	.30	1.22
4	Etonia scrub	.56	.24	3.49	29.64	57.47	5.85	.74	.22	1.56
12	High pine land	.84	1.51	5.72	23.29	47.51	17.61	.87	.34	1.87
6	Light hammock	.71	.15	3.72	28.19	53.79	8.97	1.30	.59	2.07
5	Mixed land	1.25	.06	2.62	22.05	53.55	10.99	1.79	.80	5.66
6	Rich, heavy hammock	3.97	.91	2.74	13.37	29.32	13.19	7.31	2.52	22.82
4	Lafayette	5.69	.54	1.94	8.81	35.15	13.39	3.37	1.07	29.30

The samples are arranged in the table according to the percentage of clay they contain, the least first. Leaving out of account for the moment the last three formations, which constitute a relatively small area of the peninsula proper, the other six formations, representing the important types of agricultural land supporting very different kinds of native vegetation, differ in their texture hardly more than the limit of error in the mechanical analysis. The analyses are so nearly alike that it would not be safe to consider the differences shown in the table as indicating any real difference in the texture.

In the soils of the Atlantic seaboard generally the relations of the soils to water depend mainly upon the amount of clay present in the soil. The relation of the soils to native vegetation and agricultural crops depends likewise indirectly upon the amount of clay they contain, as this determines largely the amount of water they maintain. The pine lands and the truck lands have, as a rule, not over 5 or 10 per cent of clay, while the oak and hickory soils contain not less than 20 per cent. In these Florida types, however, there is hardly more than 2 per cent of silt, fine silt, and clay all put together. The bulk of the soil consists of the two grades of medium and fine sand, but the proportion of these two grades seems to bear no relation whatever to the difference in the agricultural value of the lands.

The pineapple lands of the east coast consist of a pure white sand, with rather more of the medium grade and rather less of the grade of fine sand. With this exception there is little or no difference in the texture of the pineapple land, the gray hammock, the Etonia scrub, the high pine land, or the light hammock. There is probably no greater difference in the native vegetation of any two soils of the United States than in the gray hammock and the Etonia scrub, and yet they are seen to have the same texture, and it will appear later that they have the same chemical composition. No difference has been found, therefore, in the texture of these soils which will explain in any way the difference in their agricultural value. The rich, heavy hammock, underlaid with marl, the mixed land from the neighborhood of Ocala, and the Lafayette formation from the western part of the State differ from the other six formations principally in the amount of clay they contain.

CHEMICAL COMPOSITION OF THE SOILS.

The following table, giving the mean chemical composition of a number of Florida soils as regards several of the important plant foods, has been compiled from Bulletin No. 43 of the Florida Experiment Station:

Average chemical composition of Florida soils and subsoils.

	Hilgard's average of soils.	Florida soils.		
		Soils.	Subsoils.	Mean of all.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Potash, K_2O	0.216	0.009	0.004	0.007
Lime, CaO	.108	.072	.021	.051
Phosphoric acid, P_2O_5	.113	.071	.065	.069
Magnesia, MgO	.225	.031	.019	.026
Nitrogen, N	....	.052	.011	.035

There are thirty-four soils and twenty-three subsoils represented, while the last column gives the mean of the whole number of fifty-seven samples. The types of soils are not clearly stated in the text of the bulletin, but the samples selected represent as far as possible both the hammock and the high pine land. For comparison, Hilgard's averages for 466 soils of the humid portion of the United States are given in the first column.[1]

Hilgard states elsewhere that soils containing less than 0.1 of 1 per cent of either potash, lime, or phosphoric acid may be regarded as having a deficiency of that particular substance.

[1] Bulletin No. 3 of the United States Weather Bureau, a Report on the Relations of Soils to Climate, p. 30.

It will be seen that the food content of these Florida soils is exceedingly low. The average potash content is less than 0.01 of 1 per cent. The amounts of lime, phosphoric acid, magnesia, and nitrogen are so low that it seems almost inconceivable that such soils support such a luxuriant growth of native vegetation and are so extremely productive of the crops adapted to the climate and soil conditions. It is remarkable that soils containing so little plant food should support the vegetation found on these Florida lands.

Composite samples of five of the typical soil formations from the collection of the Department of Agriculture, and consisting in each case of from four to ten samples, were analyzed in the Division of Chemistry, with the results given in the accompanying table.

Chemical analyses of composite samples of Florida soils.

Soils.	K_2O.	CaO.	MgO.	P_2O_5.	N.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Pineapple land	0.005	0.025	0.009	0.005	0.028
Etonia scrub	.003	.030	.013	.008	.028
High pine land	.007	.060	.020	.140	.028
Light hammock	.015	.090	.040	.090	.042
Gray hammock	.009	.090	.036	.320	.042

These results show again the very small amount of plant food contained in these Florida soils. There is no difference in the chemical composition, as shown by the results of this work, which would account in any way for the difference in the native vegetation of these soils. One would not think of selecting any one of these soils from a table of analyses as adapted to the growth of hard wood trees or to oranges, tobacco, or even to truck crops.

SOLUBLE SALT CONTENT OF SOILS.

Although the analyses show a remarkably small percentage of the mineral plant foods in these soils, really within the limit of error of chemical analyses, still, on account of the enormous weight of the soils per acre, there is a very considerable amount of food material actually at the disposal of the plants. If these sandy soils are estimated to weigh 4,000,000 pounds per acre to a depth of 1 foot, there would be about 6,000 pounds per acre of potash, phosphoric acid, and lime. Calculated on the same basis, from the figures in the first column of Table 3, there is about 26,000 pounds of these plant foods present on the average in the soils of the humid regions of the United States. These figures represent the total amount of these plant foods soluble in strong hydrochloric acid. An investigation was made to determine how much of this food material was actually present in solution in the soil moisture. The determinations were made by the electrical method described in Bulletin No. 8 of this division. The results are given in the accompanying table.

Soluble salt content of Florida soils.

No.	Locality.	Soils.	In 100 grams.		In 1 acre.[1]	
			Soil.	Subsoil.	Soil.	Subsoil.
			Mg.	*Mg.*	*Pounds.*	*Pounds.*
2886	West Palmbeach	Pineapple land	0.90	0.34	36	13
2871	Winterhaven	Truck, high pine land	1.56	.80	62	32
2869	Grand Island	.....do	2.09	1.04	84	42
2915	Altoona	Scrub	.95	.94	37	38
2857	Rockledge	Orange, gray hammock	2.10	1.00	84	40
2824	Fort Meade	High pine land (first quality)	1.14	....	46	....
2817	.....do	Tobacco, heavy hammock	1.16	1.36	46	54
2826	.....do	High pine land (third quality)	1.08	1.27	43	51
2894	Quincy	Lafayette, tobacco	....	1.88	....	75

[1] Estimated to a depth of 1 foot on a basis of 4,000,000 pounds of soil per acre for this depth.

It will be seen that in no case does the amount of soluble salts present in the soil approach 100 pounds per acre to a depth of 12 inches. The hammock land at Fort Meade contains, to a depth of 1 foot, approximately only 46 pounds of mineral salts of all kinds dissolved in the soil moisture, and yet this soil produces naturally a heavy growth of hard wood trees, and is considered one of the finest soils for oranges, tobacco, truck, and similar quick-growing and exhausting crops. There is no difference in the soluble salt content, as determined by this electrical method, which would account in any way for the great difference in the native vegetation of these soils.

The chemical analyses show not only that there is a very small amount of plant food present in the soil, but these figures indicate that only about 1 per cent of this is present in a soluble form. The results so far obtained in this division indicate that the average soils of the Northern States contain upward of 1,000 pounds of mineral salts dissolved in the soil moisture, and this is approximately 5 per cent of the amount of mineral matter present soluble in strong hydrochloric acid.

These results all seem to show that these types of Florida soil constitute a distinct class of soils, unlike the average soils of the humid portions of the United States. There is no difference in the physical texture, the chemical composition, or the soluble salt content to explain the wonderful fertility and the difference in the character of the native vegetation, and one must look to other properties than those generally recognized by agricultural investigators for causes which will explain the facts. The following investigations on the relation of these soils to moisture offer a partial explanation.

MOISTURE CONTENT OF FLORIDA SOILS.

It has already been noticed that the soils of the high pine lands maintain a very uniform amount of moisture, even in seasons of protracted drought. Moisture determinations were made in the truck land at Winterhaven, Fla., during the season of 1897, with the results given in the accompanying table.

The moisture content of high pine truck land, 3 to 6 inches deep, at Winterhaven, Fla.

[Moisture determined by the electrical method.]

Day of month.	April.		May.		June.		July.	
	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.
	Per cent.	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*	*Inches.*
1	6.85		5.47	0.10	4.15		3.36	0.10
2	6.04		4.72		4.19		3.55	
3	6.01		4.29		5.13	0.31	3.44	2.95
4	5.90		4.27		4.51	.18	3.34	
5	4.53		4.31		4.15	.05	3.34	
6	5.85	0.30	4.51		3.97		3.34	
7	5.82		4.11				3.44	.30
8	9.59		4.11				3.63	
9	6.72	1.80	4.11				3.55	.30
10	5.51	.02	4.10				4.15	1.35
11	5.49		4.06		4.44		3.44	
12	4.99		4.07	.10	4.15		3.97	1.43
13	4.82		9.28	2.10	3.82		3.55	
14	4.83		5.13		3.63		3.54	
15			4.54		3.82	.23	3.44	
16	4.85		4.48		4.31	.58	3.54	
17	4.64		4.73		3.97	.02	3.55	.10
18	4.31		4.84		3.76		3.44	
19	4.27		4.49		3.55		3.55	
20	4.21		4.42		3.55		3.44	
21	4.06		4.35		13.79	.95	3.55	.47
22	4.05		4.40		4.81	.90	3.44	
23	4.06		4.35		3.97		3.55	
24	4.04		4.59		3.68	.10	3.55	.13
25	4.01		4.15		3.55		3.68	.92
26	4.04		4.31		3.68	.13	3.44	.25
27	4.04		4.27		3.51		3.68	
28	4.06		4.27		3.68		3.55	
29	4.03		4.29		3.48		3.55	.23
30	5.24	.70	4.23	.15	3.55		3.68	.35
31			4.23				3.55	.82
Mean	5.06	2.82	4.56	2.48	3.95	3.45	3.54	10.00

Four and a half per cent of water appears to be an abundant supply for the vegetables on these soils. Six per cent of moisture makes the soil quite wet. There were periods of two or three weeks without rain, and yet the moisture supply never fell below 3 per cent during the time of the observations. Furthermore, it is rather strange to note that during what is considered the dry season of April and May, with only two or three rains of any magnitude, the moisture in the soil was considerably higher than during June and July, when the rains were both heavy and frequent. This is in line with the general experience of the farmers. The moisture supply is seen to be very uniform. The effect of a rain of even 1 or 2 inches is hardly appreciable twenty-four hours after the rain has ceased. The excess of water seems to drain away very rapidly. Owing to this fact the rainfalls, where they occur in the table, seem to affect the moisture content of the soils very differently. This is owing to the difference in the time between the cessation of the rain and the taking of the observations. No reason can be assigned for the peculiar property these soils possess which enables them to maintain so uniform a water content. There were no crops growing on the soil at the time these observations were taken, so that no special demands were made upon the moisture except as a result of evaporation from the surface.

Records were also kept, by the electrical method, of the moisture content of the hammock soils at Fort Meade at a depth of from 3 to 6 inches. The results are given in the accompanying table.

The moisture content of hammock tobacco soil, 3 to 6 inches deep, at Fort Meade, Fla.

[Moisture determined by the electrical method.]

Day of month.	April.		May.		June.		July.	
	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.	Moisture.	Rain.
	Per cent.	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*	*Inches.*	*Per cent.*	*Inches.*
1	5.21	0.07	10.20	0.12			7.94	
2	5.35		10.31				7.48	0.28
3	5.32		8.32				10.53	1.32
4	5.35		7.80				8.95	
5	5.96	0.60	7.56				10.71	0.41
6		0.86	7.33				9.26	0.04
7	10.76	0.20	7.05		7.48	0.13	9.24	
8	9.58		7.09		7.45	0.55	9.22	0.15
9	13.06	0.93	7.02		7.96		10.69	0.11
10	10.31	0.30	6.77		9.05		9.21	0.07
11	9.42		6.80		7.91		10.49	0.47
12	9.30		13.63	1.30	8.06		11.00	1.96
13	9.28		11.37	1.90	7.96		10.76	1.89
14	9.13		9.24	0.30	10.83	0.59	9.66	0.14
15	8.94		11.00	1.05	8.62	0.67	8.49	
16	8.81		9.74		9.04	0.03	9.45	0.08
17	8.54				8.85		8.06	
18	8.38				7.78		8.72	0.19
19	8.06		8.23		8.16	0.17	8.51	
20	8.01		8.02		8.57	0.19	8.06	
21	7.69		7.87		8.82	0.47	7.87	
22	7.74		7.87		8.54		9.06	0.24
23	7.74		7.78		9.05		8.72	
24	7.61				8.72		8.43	
25	7.56				8.85	0.41	10.62	0.82
26	6.89				8.98		10.74	
27	6.74				8.95	0.36	8.72	
28	6.69				8.67		8.80	
29	6.69				7.45		8.12	
30	10.82	0.77			7.93		8.85	0.32
31							8.98	0.18
Mean.	7.76	3.63	[1]8.62	[1]4.67	[1]8.49	[1]3.57	9.20	8.67

[1] Excluding a period of fourteen days in May and June, during which it is not known whether rain fell or not.

It will be noticed that this hammock soil contains on an average between 8 and 9 per cent of moisture, or nearly twice as much as the truck soil at Winterhaven. Furthermore, the evaporation is very much greater and the crops suffer quicker from drought than on the high pine land. No reason can be given why such a light sandy soil as the hammock soil at Fort Meade should maintain as much as 8 per cent of water. The soils are deep and well drained, and they contain, as has been already shown, very little clay, yet the moisture content is as great as in the red lands at Quincy, Fla., which are underlaid with subsoils containing upward of 30 per cent of clay. This is a matter which needs very thorough investigation, and the very striking difference in the relation of these two types of soil to moisture will undoubtedly explain in large part the difference in the character of the native growth and in the agricultural value of the soils. It remains to be shown, also, why as little as 8 per cent of water is amply sufficient for a growth of oaks and other hard wood trees on these sandy soils of Florida, while at least 15 or 20 per cent of water is necessary for oaks and similar hard wood trees on the soils at the North. The accompanying diagram (fig. 1) shows clearly the difference in the water content of these two kinds of Florida soil.

Records were kept of the moisture content of the pineapple land at West Palmbeach in the open field and under the half shade, which is used there so successfully. The determinations were made by the old tube method, and represent the moisture content in the top foot of soil. During the dry months of April and May the soil under the shed contains, as a rule, about twice as much water as the soil in the open field. This is unquestionably an important matter at this critical time in the development of the crop. During the months of June and July, when there was an abundance of rain, there was little or no difference between the water content of the field and under the shed. The influence of the half shade in protecting the soil from loss of water during the time of protracted drought is of the utmost importance and should be more

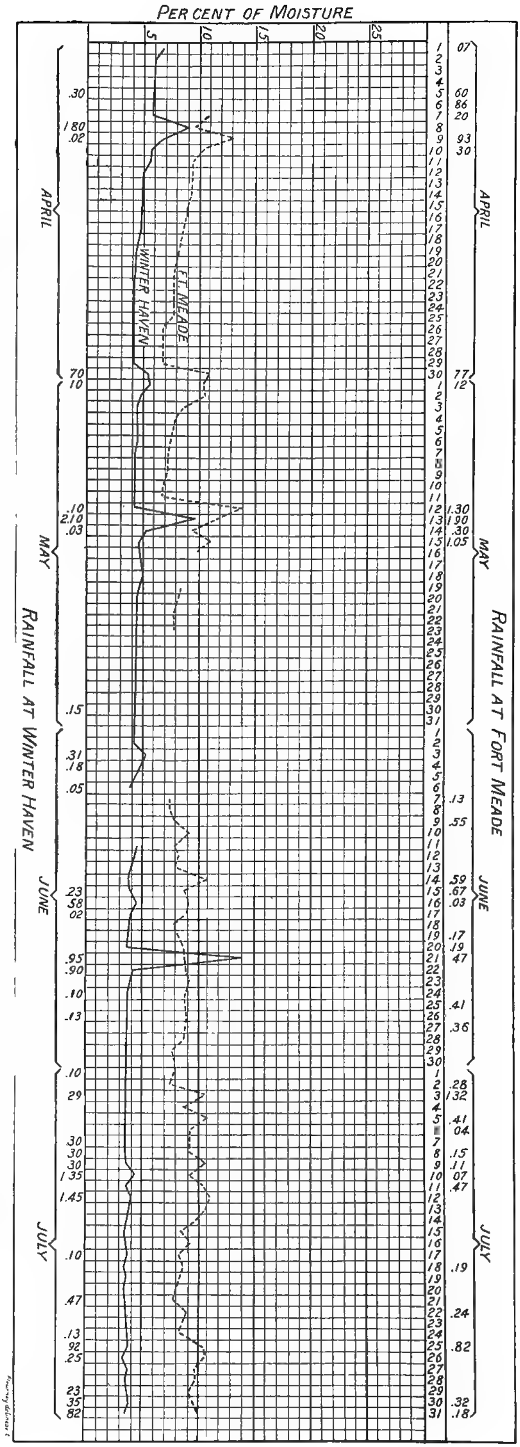
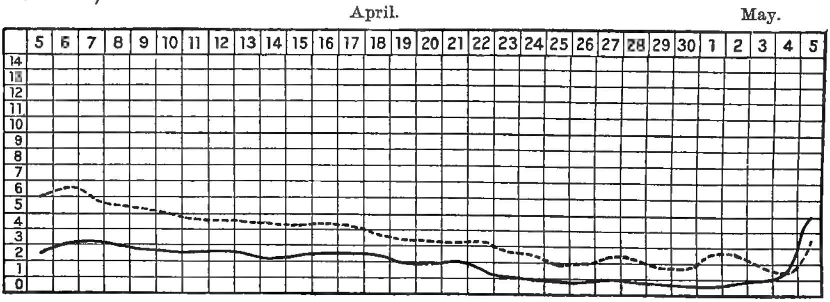


FIG. 1.—Diagram showing moisture content of the hammock soils at Fort Meade and high pine soil at Winterhaven.

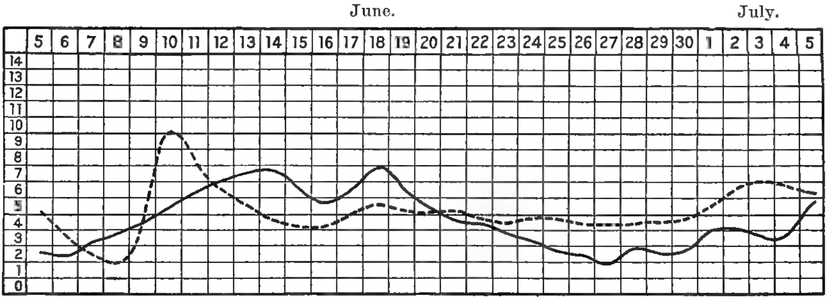
fully investigated, and records should be kept with the electrical method, which will give more reliable results, and the observations should be continued over several seasons in various kinds of soil. The accompanying table gives the data obtained from these records and the accompanying diagrams show graphically the difference in the water content of the soils during the dry period and the wet season. (Figs. 2 and 3.)



—— Open field. ...... Under shed.

[Numerals on left indicate per cent of moisture.]

FIG. 2.—Diagram showing influence of half shading in conserving moisture in pineapple land at West Palmbeach, Fla., during dry season. Showers are reported on April 17, 18, 21, May 3, 4, 5—amount not stated.



—— Open field. ...... Under shed.

[Numerals on left indicate per cent of moisture.]

FIG. 3.—Diagram illustrating conditions in pineapple land in open field and under half shade at West Palmbeach, Fla., during rainy season. Pineapples ripening and being shipped.

Pineapple land at West Palmbeach, Fla., 1896.

Day.	April.			May.			June.			July.		
	Field.	Shed.	Weather.	Field.	Shed.	Weather.	Field.	Shed.	Weather.	Field.	Shed.	Weather.
	Per ct.	*Per ct.*		*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*	
1	....	....	....	0.6	2.5	....	0.5	0.4	....	4.0	5.4	
2	....	....	Rain..	.8	2.5	....	1.2	.1	....	4.0	6.5	
3	....	....	....	1.0	1.8	....	6.0	4.0	Rain..	3.5	7.0	Rain.
4	....	....	....	1.5	1.5	Rain..	4.0	5.4	Rain..	3.6	6.6	
5	2.5	6.0	....	5.0	3.4	Rain..	2.5	5.2	Rain..	5.8	6.4	Rain.
6	3.0	6.5	....	4.0	6.5	Rain..	2.3	3.6	....	5.3	6.3	Rain.
7	3.2	6.0	....	3.0	6.4	Rain..	3.2	2.6	Rain..	5.1	6.8	
8	3.0	5.6	....	2.0	2.6	....	3.8	2.0	....	5.0	7.0	Rain.
9	2.8	5.3	....	1.5	1.8	....	4.6	4.0	Rain..	4.5	6.0	Rain.
10	2.5	5.0	....	1.3	1.8	....	5.5	10.0	Rain..	4.8	3.5	
11	2.5	4.8	....	1.5	3.0	....	6.4	8.0	....	3.0	2.0	Rain.
12	2.6	4.8	....	2.0	3.8	....	7.0	6.5	Rain..	2.6	1.2	
13	2.4	4.6	....	2.4	4.0	....	7.5	5.6	Rain..	2.0	1.2	
14	2.1	4.4	....	2.4	2.5	....	7.8	4.8	Rain..	2.0	1.8	
15	2.3	4.3	....	2.2	3.0	....	6.5	4.2	Rain..	2.1	2.4	

Pineapple land at West Palmbeach, Fla., 1896—Continued.

Day.	April. Field.	April. Shed.	April. Weather.	May. Field.	May. Shed.	May. Weather.	June. Field.	June. Shed.	June. Weather.	July. Field.	July. Shed.	July. Weather.
	Per ct.	*Per ct.*		*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*	
16	2.5	4.3	....	1.5	2.8	....	5.7	4.1	....	2.6	3.4	
17	2.5	4.2	Rain..	.8	3.0	....	6.5	5.0	....	3.6	4.4	
18	2.4	3.8	Rain..	.4	2.1	....	8.0	5.6	....	5.0	5.4	
19	2.0	3.5	....	.3	2.2	....	6.6	5.2	....	6.0	6.0	Rain.
20	2.0	3.3	....	.4	3.0	....	5.6	5.1	....	5.1	5.5	
21	2.1	3.2	Rain..	.6	2.8	Rain..	4.8	5.2	....	4.5	5.1	
22	1.5	3.2	....	1.0	2.6	Rain..	4.4	4.8	....	3.6	5.0	
23	1.1	2.9	....	1.3	2.6	Rain..	3.8	4.4	....	3.0	5.0	
24	1.0	2.5	....	1.8	2.2	....	3.3	4.8	....	2.5	5.1	
25	.9	2.0	....	2.4	1.8	....	2.7	4.8	....	2.0	5.2	
26	.9	2.0	....	2.1	1.8	Rain..	2.4	4.3	....	1.8	4.5	
27	1.0	2.2	....	2.0	1.6	....	1.9	4.3	....	1.6	3.5	
28	.8	2.1	....	1.8	1.5	....	2.8	4.3	Rain..	1.5	1.8	
29	.7	1.8	....	1.9	1.5	Rain..	2.4	4.4	Rain..	1.5	1.6	
30	.6	1.7	....	1.8	1.3	Rain..	2.8	4.7	Rain..	1.0	1.6	
31	....	....	....	1.1	1.8	....	....	....	....	1.0	1.4	
	2.0	3.8	....	1.7	2.6	....	4.4	4.6	....	3.3	4.3	

A series of moisture determinations were made in the scrub and the adjacent high pine land at Altoona for a period of two months during the season of 1896. The determinations were made by the old method of taking samples of the soil in small brass tubes and sending them, protected from evaporation, to the laboratory of the Department, where careful moisture determinations were made. The results of these daily observations were then platted and a curve drawn through the mean positions occupied by the actual points of observation. The mean daily readings, as thus deduced, are given in the accompanying table:

Water content of high pine and scrub land at Altoona, Fla., in 1896.

Day of month.	April. Pine land.	April. Scrub.	May. Pine land.	May. Scrub.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
1	....	....	4.2	4.5
2	4.7	5.8	3.8	3.6
3	4.0	5.0	3.4	2.9
4	3.3	4.1	3.0	2.4
5	2.9	3.5	2.6	2.0
6	2.4	2.9	2.3	1.7
7	2.0	2.4	2.0	1.4
8	1.4	1.9	1.8	1.1
9	7.0	6.8	1.5	1.0
10	4.9	5.5	1.3	.9
11	4.4	4.6	1.1	.8
12	4.0	4.1	....	....
13	3.7	3.7	....	....
14	3.4	3.2	....	....
15	3.0	2.8	....	....
16	2.7	2.5	3.3	3.8
17	2.5	2.1	3.1	3.3
18	2.2	1.9	2.9	2.8
19	2.1	1.5	2.7	2.4
20	1.9	1.3	2.6	2.0
21	1.8	2.5	2.4	1.7
22	1.6	2.1	2.3	1.5
23	1.5	1.9	2.1	1.3
24	1.4	1.6	2.0	1.1
25	1.3	1.4	1.9	.9
26	1.2	1.2	1.8	.8
27	1.1	1.0	1.7	.7
28	1.0	.9	1.6	.6
29	1.0	.8	1.5	.6
30	4.7	5.5	2.7	2.9
31	....	....	2.4	2.5
Mean	2.7	2.9	2.4	1.9

The records show that there is no apparent difference in the moisture content of these two soils during the dry season, and there is nothing here which suggests any difference in the water content of the soils to explain the difference in the relation of these soils to crops and to the native vegetation. The amount of water in each appears to be very small, but on the high pine lands the conditions are favorable for vigorous growth for the most tender vegetables. The native growth in the scrub, on the other hand, shows the main characteristics of desert plants and of arid conditions. With an apparently equal moisture supply, plants on one soil appear to get all the moisture they require, while the plants on the other soil, having the same texture and the same chemical composition, have all the appearance of having been grown under extremely arid conditions.

The following table gives the detailed results of the mechanical analyses of the Florida samples:

Mechanical analyses of soils and subsoils.

No.	Locality.	Description.	Moisture in air-dry sample.	Organic matter.	Gravel (2-1 mm.).	Coarse sand (1-0.5 mm.).	Medium sand (0.5-0.25 mm.).	Fine sand (0.25-1 mm.).	Very fine sand (0.1-0.05 mm.).	Silt (0.05-0.01 mm.).	Fine silt (0.01-0.005 mm.).	Clay (0.005-0.0001 mm.).
			P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.	P. ct.
2212	West Palm-beach.	Pineapple land, 0″-6″	0.09	0.59	0.91	3.43	65.29	29.98	0.17	0.08	0.08	0.37
2890	......do	Pineapple land, 0″-6″	.11	.99	.00	2.30	57.12	38.52	.83	.13	.05	.40
2886	......do	Pineapple land, 0″-6″	.16	1.37	.00	4.03	65.79	27.55	.50	.50	.02	.52
2888	......do	Pineapple land, 0″-6″	.23	1.87	.00	2.30	56.23	38.98	.67	.17	.07	.70
	Average	....	.15	1.21	.23	3.02	61.11	33.76	.54	.22	.06	.50
2887	West Palm-beach.	Pineapple land, 6″-30″.	0.02	0.14	0.00	3.33	60.25	34.57	1.14	trace	trace	trace
2213	.....do	Pineapple land, 12″-18″.	.02	.12	.08	3.01	58.34	37.79	.23	0.05	0.13	0.20
2891	.....do	Pineapple land, 6″-36″.	.07	.07	.00	1.84	51.79	44.89	.94	.13	.08	.35
2214	.....do	Pineapple land, subsoil.	.08	.30	.16	4.77	60.19	33.36	.30	.07	.31	.72
2889	.....do	Pineapple land, 6″-36″.	.18	.90	.04	2.45	56.92	38.28	.32	.12	.11	1.35
	Average	....	.07	.31	.06	3.08	57.50	37.78	.59	.07	.13	.52
2867	Rockledge	Spruce-pine scrub, 0″-6″.	0.18	0.53	0.45	12.60	40.30	42.88	2.44	0.11	0.07	0.19
2865	.....do	Spruce-pine scrub, 0″-6″.	.11	1.59	.84	12.12	42.54	39.48	2.36	.21	.04	.50
	Average	....	.15	1.06	.65	12.36	41.42	41.18	2.40	.16	.06	.35
2866	Rockledge	Spruce-pine scrub, 6″-36″.	0.25	0.45	0.66	9.07	32.58	52.13	3.26	0.23	0.18	0.51
2827	Ocala	Light hammock, 0″-9″.	.35	1.16	trace	1.59	15.63	62.87	15.70	1.25	.48	.61
2871	Winterhaven .	Light hammock, 0″-8″.	.47	.59	trace	5.96	37.90	47.35	5.00	.73	.25	1.24
2830	Ocala, one-half mile south.	Light hammock, 0″-12″.	.49	1.36	trace	3.07	21.44	53.54	13.30	2.68	1.33	2.39
2873	Winterhaven .	Light hammock, 0″-9″.	.66	2.39	trace	3.89	40.44	41.71	7.35	.84	.42	2.55
	Average .	....	.49	1.48	trace	3.63	28.85	51.37	10.34	1.38	.62	1.70
2872	Winterhaven .	Light hammock, 8″-36″.	.02	.24	trace	6.46	42.00	43.49	3.96	.94	.23	1.21

Mechanical analyses of soils and subsoils—Continued.

No.	Locality.	Description.	Moisture in air-dry sample.	Organic matter.	Gravel (2-1 mm.).	Coarse sand (1-0.5 mm.).	Medium sand (0.5-0.25 mm.).	Fine sand (0.25-1 mm.).	Very fine sand (0.1-0.05 mm.).	Silt (0.05-0.01 mm.).	Fine silt (0.01-0.005 mm.).	Clay (0.005-0.0001 mm.).
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
2829	Ocala	Light hammock, 24″-36″.	0.30	0.65	trace	1.45	19.63	62.40	11.65	1.80	0.62	1.26
2828	.....do	Light hammock, 9″-24″.	.22	.75	trace	1.80	18.25	65.37	10.07	1.20	.55	1.39
2847	Silverspring	Light hammock, 12″-24″.	.19	.40	.62	5.57	28.66	52.74	9.84	.38	.20	1.82
2831	Ocala, one-half mile south.	Light hammock, 12″-30″.	.32	.92	.28	3.30	22.29	55.29	10.64	2.62	1.64	3.06
2874	Winterhaven	Light hammock, 9″-30″.	.48	1.27	trace	3.74	38.30	43.47	7.67	.87	.28	3.68
	Average		.26	.71	.15	3.72	28.19	53.79	8.97	1.30	.59	2.07
2895	Quincy	Lafayette, 0″-12″	.33	1.63	.13	1.61	9.48	56.76	20.82	3.75	.81	4.37
2897	.....do	Lafayette, 0″-12″	.84	4.35	1.01	5.35	18.33	40.86	14.49	4.31	.99	7.95
2899	.....do	Lafayette, 0″-9″	.71	3.32	.45	2.10	19.25	47.37	15.28	4.99	.92	5.61
2901	.....do	Lafayette, soil	.43	1.41	1.11	10.33	33.07	37.18	9.14	3.53	.49	2.65
	Average		.58	2.68	.68	4.85	20.03	45.53	14.93	4.15	.80	5.15
2895	Quincy	Lafayette, 12″-36″	.53	4.00	.18	1.45	9.38	46.30	14.16	4.70	.88	18.16
2900	.....do	Lafayette, 9″-30″	1.31	5.89	.59	1.55	8.11	34.36	15.27	3.48	.77	29.15
2896	.....do	Lafayette, subsoil	1.31	5.94	.51	1.24	6.06	33.41	13.58	2.79	1.74	34.15
2898	.....do	Lafayette, 12″-12″	1.55	6.92	.88	3.52	11.68	26.54	10.54	2.51	.88	35.73
	Average		1.18	5.69	.54	1.94	8.81	35.15	13.39	3.37	1.07	29.30
2857	Rockledge	Heavy (gray) hammock, 0″-18″.	.26	.92	.18	4.80	31.31	58.80	2.07	.23	.09	.85
2819	Fort Meade	Heavy (gray) hammock, 0″-30″.	1.06	2.50	.80	3.81	13.77	50.10	24.41	.90	.55	.99
2859	Rockledge	Heavy (gray) hammock, 0″-18″.	.13	.74	.16	3.50	33.00	61.19	.98	.18	.83	1.03
2820	Fort Meade	Heavy (gray) hammock, 0″-20″.	1.39	2.88	.25	1.36	7.76	41.75	41.22	1.22	.70	1.58
2817	.....do	Heavy (gray) hammock, 0″-20″.	.94	2.13	.41	2.97	12.92	48.99	26.69	.74	.30	3.93
	Average		.76	1.84	.36	3.29	19.75	52.17	19.08	.66	.50	1.68
2860	Rockledge	Heavy (gray) hammock, 18″-36″.	.27	.66	.19	3.99	28.76	63.78	1.42	.14	.14	.13
2858	.....do	Heavy (gray) hammock, 18″-36″.	.16	.55	.11	5.49	35.75	54.75	1.20	.01	.06	.14
2821	Fort Meade	Heavy (gray) hammock, 20″-36″.	1.03	2.16	.36	1.40	8.30	48.87	35.36	1.00	.52	1.17
2818	.....do	Heavy (gray) hammock, 20″-36″.	1.06	3.06	.40	4.29	19.15	46.70	20.19	.78	.47	3.44
	Average		.63	1.61	.27	3.79	22.99	53.53	14.54	.48	.30	1.22
1621	Altoona	Etonia scrub, 0″-4″	.12	1.13	.56	3.43	35.90	51.00	6.27	1.01	.28	.54
2915	.....do	Etonia scrub, 0″-3″	.34	1.78	.16	4.54	33.21	53.64	4.46	.41	.18	.64
2917	Orange City Junction	Etonia scrub, 0″-6″	.21	1.00	.00	.33	5.58	75.33	16.66	.40	.18	.75
2913	Altoona	Etonia scrub, 0″-4′	.19	1.04	.18	5.06	35.03	54.44	3.02	.37	.15	1.53
	Average		.22	1.24	.23	3.34	27.43	58.60	7.60	.55	.20	.87
1622	Altoona	Etonia scrub, 6″-18″	.68	1.13	.34	3.92	40.39	44.97	6.96	.79	.33	1.16
2916	.....do	Etonia scrub, 3″-30″	.05	1.78	.27	4.87	36.31	51.69	2.14	1.34	.10	1.45
2918	Orange City Junction.	Etonia scrub, 6″-36″	.17	1.00	.00	.23	5.70	79.84	11.46	.52	.27	1.73
2914	Altoona	Etonia scrub, 4″-36″	.17	1.04	.34	4.94	36.15	53.16	2.82	.32	.18	1.90
	Average		.28	1.24	.24	3.49	29.64	57.47	5.85	.74	.22	1.56
2861	Rockledge	Red coquina hammock, 0″-6″.	.93	3.64	.66	10.85	37.31	38.34	5.50	.67	.19	1.03
2863	.....do	Red coquina hammock, 0″-4″.	1.54	6.85	.68	10.44	28.03	39.38	9.93	.95	.39	1.62
	Average		1.24	5.25	.67	10.65	32.67	38.86	7.72	.81	.29	1.33

Mechanical analyses of soils and subsoils—Continued.

No.	Locality.	Description.	Moisture in air-dry sample.	Organic matter.	Gravel (2-1 mm.).	Coarse sand (1-0.5 mm.).	Medium sand (0.5-0.25 mm.).	Fine sand (0.25-1 mm.).	Very fine sand (0.1-0.05 mm.).	Silt (0.05-0.01 mm.).	Fine silt (0.01-0.005 mm.).	Clay (0.005-0.0001 mm.).
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
2862	Rockledge	Red coquina hammock, 6″-36″.	0.52	0.67	0.78	12.56	36.93	41.46	4.56	0.45	0.24	2.00
2864	....do	Red coquina hammock, 4″-18″.	.55	2.02	.49	9.35	27.59	46.58	8.67	1.15	.47	2.52
	Average		.53	1.35	.64	15.96	32.26	44.02	6.62	.80	.36	2.26
2822	Fort Meade	Mulatto hammock 0″ 12″.	.62	1.53	.78	2.85	14.35	53.51	23.50	.65	.44	2.07
2823	Fort Meade	Mulatto hammock subsoil.	.47	1.43	.70	2.50	14.30	53.00	24.46	.62	.34	1.58
2869	Grand Island	High pine land, 0″-8″.	.12	1.43	7.60	18.32	27.88	38.45	3.35	.86	.22	.67
1619	Altoona	High pine land, 0″-6″.	.23	1.27	1.98	5.18	12.93	27.48	45.87	2.78	.73	.81
2875	Winterhaven	High pine land, 0″-8″.	.26	1.31	.01	2.88	35.01	51.28	7.70	.75	.25	1.03
1623	Eustis	High pine land, 0″-6″.	.54	1.75	2.31	11.52	44.76	30.90	4.40	1.14	1.02	1.10
2911	Altoona	High pine land, 0″-4″.	.25	1.25	.47	7.49	38.09	49.42	2.29	.31	.15	1.13
2879	Winterhaven	High pine land,[2] 0″-8″.	.13	.80	.05	7.66	44.40	40.52	4.66	.51	.22	1.15
2906	Altoona	High pine land, 0″-8″.	.47	1.65	1.39	3.51	8.71	55.17	26.21	.93	.28	1.26
2908	....do	High pine land, 0″-8″.	.39	2.00	2.61	4.64	13.69	60.28	15.33	.60	.24	1.38
2826	Fort Meade	High pine land,[2] 0″-18″.	.47	1.60	.10	.65	4.58	47.88	40.90	.58	.23	1.68
2824	Fort Meade, one-half mile south.	High pine land,[1] 0″-20″.	1.54	3.02	.52	2.94	16.00	47.95	24.73	.86	.38	2.62
2852	Bartow	High pine land, 0″-9″.	.81	3.37	.35	2.21	20.83	46.70	21.89	1.24	.41	2.83
2850	....do	High pine land, 0″-9″.	.55	2.44	.17	2.31	19.74	45.32	25.71	.97	.38	3.05
	Average		.48	1.82	1.46	5.78	23.89	45.11	18.42	.96	.38	1.56
2912	Altoona	High pine land, 4″-30″.	.13	.53	.63	7.30	34.92	51.11	3.47	.44	0.22	1.00
2870	Grand Island	High pine land, 8″-36″.	.14	.65	7.40	15.87	24.63	44.09	3.87	1.12	.28	1.15
1624	Eustis	High pine land, 6″-18″.	.25	.66	2.74	11.70	42.05	35.29	4.50	.88	.56	1.23
2909	Altoona	High pine land, 8″-36″.	.16	.68	2.69	5.27	13.01	61.92	14.64	.75	.28	1.25
2876	Winterhaven	High pine land, 8″-36″.	.12	.32	.03	3.59	37.41	48.77	7.88	.66	.27	1.30
2907	Altoona	High pine land, 8″-36″.	.29	.67	1.89	3.34	6.86	53.30	29.71	1.20	.33	1.30
1620	....do	High pine land, 6″-18″.	.15	.87	1.61	4.52	12.28	27.58	48.12	2.16	.81	1.31
2880	Winterhaven	High pine land,[2] 8″-30″.	.16	.36	.16	9.70	47.41	37.72	2.76	.48	.23	1.35
2920	Fort Meade	High pine land,[2] 18″-36″.	.30	.82	.11	.71	6.19	64.37	24.59	.73	.40	2.15
2825	Fort Meade, one-half mile south.	High pine land,[1] 20″-30″.	.48	2.22	.52	3.14	17.23	49.29	23.14	.62	.30	2.62
2853	Bartow	High pine land, 9″-30″.	.54	1.24	.24	1.61	17.91	49.22	24.98	.78	.24	3.60
2851	....do	High pine land, 9″-30″.	.36	1.09	.10	1.83	19.57	48.41	23.66	.65	.21	4.15
	Average		.28	.84	1.51	5.72	23.29	47.51	17.61	.87	.34	1.87
2837	Ocala	Mixed lands, 0″-12″	.39	1.63	.09	4.07	32.31	44.72	11.10	2.55	.53	2.09
2845	....do	Mixed lands, soil	.31	1.34	.10	1.95	24.46	60.25	9.59	.42	.19	2.10

[1] First quality high pine land.

[2] Third quality high pine land.

Mechanical analyses of soils and subsoils—Continued.

No.	Locality.	Description.	Moisture in air-dry sample.	Organic matter.	Gravel (2–1 mm.).	Coarse sand (1–0.5 mm.).	Medium sand (0.5–0.25 mm.).	Fine sand (0.25–1 mm.).	Very fine sand (0.1–0.05 mm.).	Silt (0.05–0.01 mm.).	Fine silt (0.01–0.005 mm.).	Clay (0.005–0.0001 mm.)
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
2839	Ocala, 2 miles south.	Mixed lands, 0″–12″	0.78	1.56	trace	2.12	16.88	57.57	11.30	2.26	1.27	5.19
2842	Ocala	Mixed lands, 0″–9″	1.11	3.46	trace	3.50	32.95	34.15	10.64	2.96	.95	9.63
	Average		.65	2.00	.05	2.91	26.65	49.17	10.66	2.05	.74	4.75
2838	Ocala	Mixed lands, 12″–36″	.06	.49	trace	3.15	24.94	51.10	13.47	2.33	1.10	2.29
2841	Ocala, 2 miles south.	Mixed lands, 24″–36″	.41	1.10	trace	1.90	13.83	63.70	12.85	2.06	.94	2.48
2846	Ocala	Mixed lands, subsoil	.24	.72	.32	2.42	27.55	57.44	6.84	.50	.24	3.00
2840	Ocala, 2 miles south.	Mixed lands, 12″–24″	.19	.72	trace	1.95	13.15	62.53	12.35	1.81	.87	5.85
2843	Ocala	Mixed lands, 9″–24	1.41	3.20	trace	3.67	30.80	33.00	9.45	2.24	.87	14.66
	Average		.46	1.25	.06	2.62	22.05	53.55	10.99	1.79	.80	5.66
1625	Altoona	Rich heavy hammock, 0″–6″.	.16	1.38	.96	.22	12.52	46.50	29.69	2.07	.50	.92
2884	Orange Bend	Rich heavy hammock, 0″–8″.	.44	1.77	.45	4.92	35.77	42.85	6.49	2.33	.54	4.58
2834	Ocala	Rich heavy hammock, 0″–12″.	1.61	4.94	.27	2.16	17.01	40.94	20.26	5.61	2.23	5.55
2832	Ocala, 2½ miles south.	Rich heavy hammock, 0″–12″.	1.39	2.61	1.58	2.62	13.08	46.32	19.83	3.38	1.50	6.86
	Average		.90	2.68	.82	2.48	19.60	44.15	19.07	3.35	1.19	4.48

BULLETIN No. 14. S. 21.

U. S. DEPARTMENT OF AGRICULTURE.

DIVISION OF SOILS.

THE

ALKALI SOILS OF THE YELLOWSTONE VALLEY

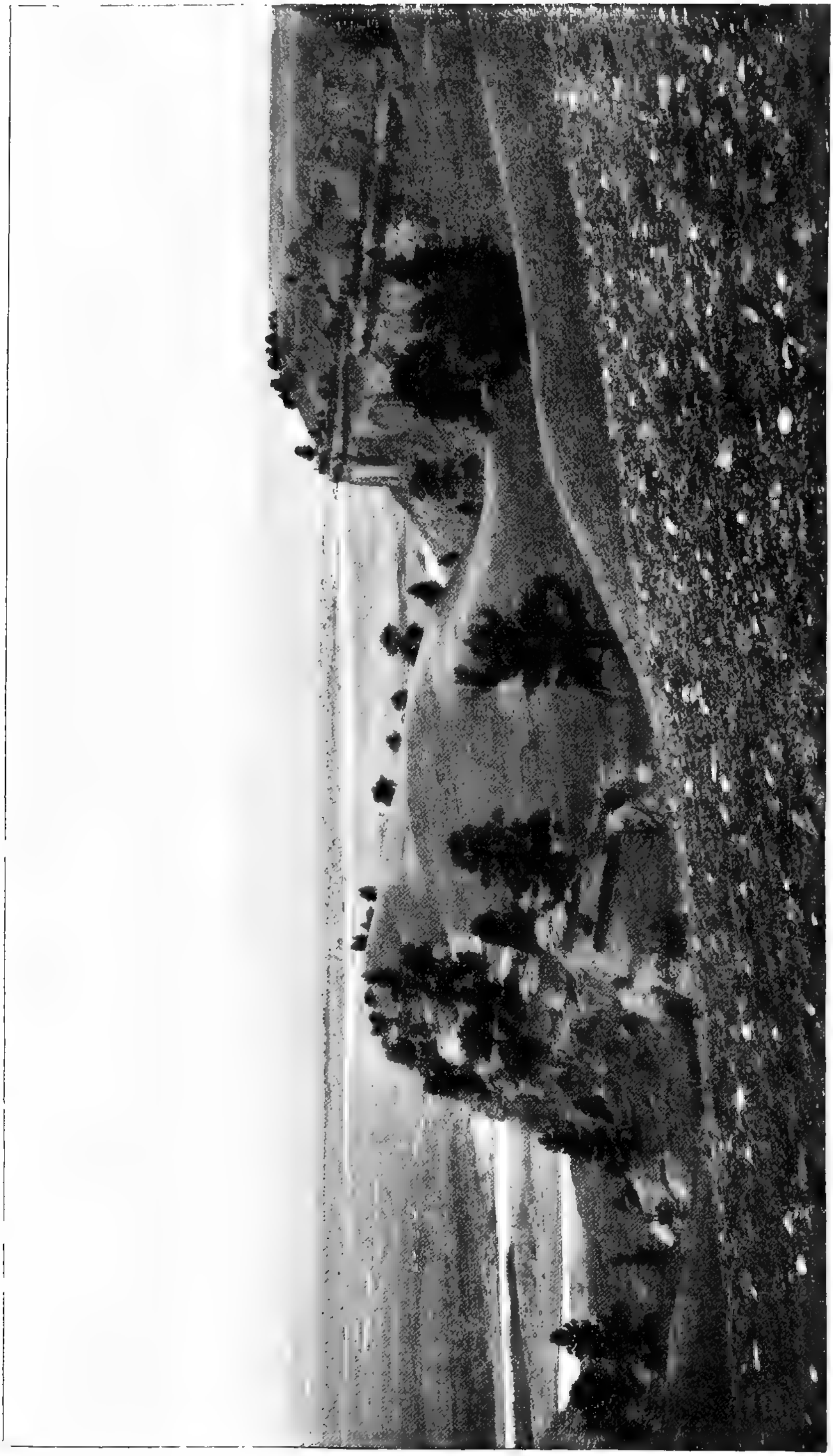
FROM

A PRELIMINARY INVESTIGATION OF THE SOILS NEAR BILLINGS, MONTANA.

BY

MILTON WHITNEY and THOS. H. MEANS.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1898.



THE YELLOWSTONE VALLEY FROM THE BLUFF OVERLOOKING THE TOWN OF BILLINGS.

This portion of the valley, once fertile, is now for the most part unfit for agricultural crops on account of the seepage waters and excess of alkali.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
DIVISION OF SOILS,
Washington, D. C., October 22, 1898.

SIR: I have the honor to transmit herewith the manuscript for a bulletin on the results of some investigations of the alkali soils of the Yellowstone Valley. The manuscript is very fully illustrated in order that the practical side of the work can be plainly shown. Plates I–V, XVI, XVII, are from photographs taken by A. B. Rumsey, Billings, Mont. Plate XV is from a photograph by Dr. F. W. Traphagen of Bozeman, Mont.

I recommend that this be published as Bulletin No. 14 of this division.

Respectfully,

MILTON WHITNEY,
Chief of Division.

Hon. JAMES WILSON,
Secretary of Agriculture.

PREFACE.

In August, 1897, I had a conference with the general manager and the land commissioner of the Northern Pacific Railroad at St. Paul, Minn., in regard to the character of the land through which their road runs and through which I expected to pass in a trip of reconnoissance through the Northwest. They both urged me to stop at Miles City and Billings, Mont., in the Yellowstone Valley, to investigate the alkali lands. They stated that serious trouble was threatened at these places from the rise of alkali in the soils. In opening up the country there had been no suggestion of trouble with alkali, and it was only beginning to assume alarming proportions now after some ten or twelve years of irrigation.

I stopped at Billings, and was driven over a large area of the valley at that place by several gentlemen interested in the matter. The conditions seemed so very important and there was so much uncertainty as to exactly what the conditions were under the surface that I sent back to Washington for an equipment for the electrical determination of the salt content of the soils, and returned to Billings when notified that this had arrived. The brief examination that was possible in the short time at my disposal satisfied me that further investigations would give results of very great practical value by showing the farmers just what the conditions were in the soil; what they had to fear if existing methods were continued; what they had to guard against to prevent the spread of alkali, and what they would have to contend with in reclaiming some of the already abandoned lands.

The following spring Mr. Thomas H. Means, an assistant in this division, was sent out to Billings to make a more detailed investigation. Owing to the small amount of money available he was only able to stay there about six weeks, but he was charged to collect data as to the general distribution of the salts with reference to the topography of the land and the position of the irrigating ditch, and to make such a detailed examination of a small area that an underground map could be constructed, showing the amount and distribution of the alkali salts under the surface. This work has been very thoroughly done, as will appear in the following pages.

The results of this investigation appear of so much practical value that arrangements are being made to continue the work and to make an underground survey of the entire valley. It is estimated that in six months' time and at an expense not exceeding $1,200, a sum utterly insignificant in proportion to the great value of the probable results of such an expedition, the necessary data could be collected from Billings eastward to Miles City or possibly Glendive and suitable underground maps prepared, with a view to preventing such serious calamities as have overtaken some of these lands in opening up new districts and for the reclamation of abandoned irrigated lands in the Yellowstone Valley. I sincerely trust that arrangements may be consummated for the completion of this survey.

It must not appear to those unacquainted with the subject that the rise of alkali and the disastrous effects following the application of irrigation waters is peculiar to the Yellowstone Valley. These are problems which have to be confronted in all arid regions the world over and wherever irrigation is practiced. The Yellowstone Valley was really selected to start the alkali work of the division because there the problem is so simple and the conditions can be so easily controlled. All of the irrigation districts of the country contain more or less alkali and are subject to the evil effects of overirrigation, and the community is to be congratulated where the conditions are so simple and so easily controlled as in the Yellowstone Valley.

M. W.

CONTENTS.

ILLUSTRATIONS.

TEXT FIGURES.

PLATES.

THE ALKALI SOILS OF THE YELLOWSTONE VALLEY.

INTRODUCTION.

The Yellowstone Valley in Montana is approximately 400 miles in length, but the area which has been especially considered in these investigations is that part of the valley between Billings and Glendive, a distance of about 250 miles. All of the detailed work, however, mentioned in this report was done in the immediate vicinity of Billings. The valley at this point is about 6 miles in width. Irrigation has been practiced for twelve or fifteen years. The water for the main ditch supplying the valley at this point is taken out of the river nearly 40 miles above the town of Billings.

When the country was first settled and, indeed, above the ditch at the present time, the depth to standing water in the wells was from 20 to 50 feet, and there were no signs of alkali on the surface of the ground. Under the common practice of irrigation, however, an excessive amount of water has been applied to the land, and seepage waters have accumulated to such a degree that water is now secured in wells at a depth of from 3 to 10 feet in the irrigated district, while many once fertile tracts on the lower levels are already flooded, and alkali has accumulated on them to such an extent that they are mere bogs and swamps and alkali flats, and the once fertile lands are thrown out as ruined and abandoned tracts. This injury, while not very widespread as yet, has been so serious where the results have appeared that the owners of the land are naturally very much concerned. Fortunately they are prepared to receive kindly and to take advantage of all the information that can be thrown upon the condition.

Many theories have been advanced by the landowners as to the source of the alkali and as to the conditions under the surface. The belief is widespread that the alkali flats could probably be reclaimed by flooding the surface during a dry season and washing the crust off. Our preliminary investigations showed them plainly that the crust contained only a small proportion of the alkali, and convinced them that this method would not be efficient. They are beginning to realize, however, that the less water they use the safer; but still many of the planters distrust this suggestion as a possible device of the ditch management to restrict the use of water in order that it may go further and supply a larger number of customers.

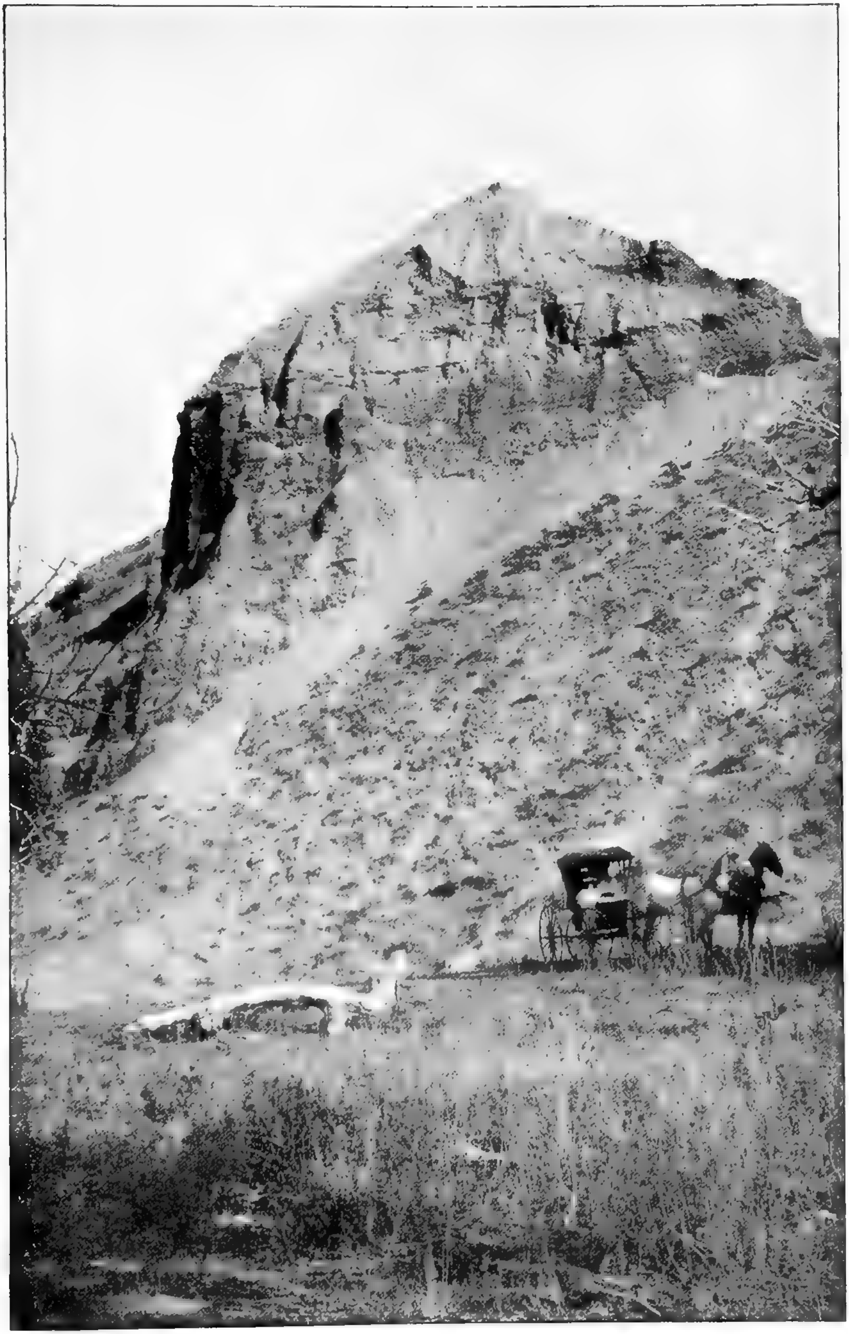
There is generally little system in the application of water to the land. Very few of the planters know how much they use, and none of them pretend to know how much they need. The water is applied when the surface appears dry, and it is then applied in such excess that much of it can not evaporate and can not seep down through the subsoil before the surface again dries out and a further heavy application of water is applied by flooding. The planters do not realize (indeed, how can they, not seeing the conditions under the surface) that the water is accumulating there, and although it may not be rising rapidly enough to injure themselves, it may be seeping down and gradually inundating their unfortunate neighbors on lower levels. In every case of injury to crops which was examined around Billings the first trouble was shown to be an accumulation of seepage water near the surface of the ground. This water is not at first excessively alkaline, but from the continual evaporation of so much water from the surface the soluble salts accumulate to an excessive and ruinous extent, prejudicial to the growth of all cultivated plants.

Hilgard has been pointing out for years that the only safe practice in bringing a new area under the ditch, in a soil which is at all likely to have alkali, is to use water very sparingly and to keep the surface under very thorough cultivation so that a minimum amount of water shall evaporate from the surface of the ground and that there shall be no accumulation of seepage waters in the subsoil.

If these investigations do no more than to show the full results of overirrigation and the necessity of intelligent and careful application of water to the soil and the importance of underdrainage, where the alkali can not be otherwise controlled or removed, the authors will be well repaid.

Proper irrigation in an arid region furnishes an ideal condition of crop production. In practice, however, the method of applying water to the land is extremely crude, and there is really little cause to wonder that much harm has been done through overirrigation, and it is no wonder that very serious trouble has occurred through the rise of soluble salts. There is less excuse for this wasteful use of water now, however. In the first place water is more valuable, and if three areas can be supplied with sufficient water from what is now applied on one area it would result not only in the advantage of an increased area brought under the ditch, but in the distinct advantage of a smaller application per acre. Furthermore, we understand now that different plants require different amounts of water for their best development, and even that the same crop requires varying amounts of water during the various periods of its development. Different soils require different amounts of water, depending upon their texture.

There is reason to hope that these principles will come to be recognized and controlled in the field as they are in the commercial greenhouses of the present time. Furthermore, the Division of Soils has invented (described heretofore) a very ingenious instrument for determining the moisture content of soils through their electrical resistance. With this instrument the amount and fluctuations of the water content near the surface of the ground or at any desired depth can be readily



A NEAR VIEW OF THE SLATE BLUFF SOUTH OF THE RIVER, WITH THE TALUS SLOPE FORMED FROM THE DISINTEGRATION AND BREAKING DOWN OF THE ROCKS.

These rocks are filled with veins of gypsum and alkali salts.

determined, and by the use of such instrument it is quite possible, with an irrigation plant, to maintain any desired water content near the surface, and to prevent an undue accumulation in the subsoil. So important is this considered that a very simple and cheap modification of the instrument has been devised for use in irrigated fields, to cost probably not over $10 apiece, so that for a moderate expense enough of these could be distributed, even over a large plantation, so that the fluctuations of the water content of the soils of the different fields could be closely studied and controlled.

ORIGIN OF THE ALKALI SALTS.

Any excessive accumulation of soluble mineral salts in the soil is popularly spoken of as "alkali" in the West. The term, therefore, as popularly used and as used in this bulletin, does not necessarily refer to material of an alkaline or basic nature. The alkali soils of the West are of two principal classes: The alkaline carbonates, or black alkali, usually sodium carbonate, is the worst form of alkali, actually dissolving the organic materials of the soil and corroding and killing the germinating seed or roots of plants; the white alkalies, the most common of which are sodium sulphate, sodium chloride, magnesium sulphate, magnesium chloride, and occasionally, as in northern Nevada, some of the borates, are not in themselves poisonous to plants, nor do they attack the substance of the plant roots, but are injurious when, owing to their presence in excessive amounts, they prevent the plants from taking up their needed food and water supply.

Field work in the alkali soils at Billings has shown that when the concentration of the salts in active solution in the soil moisture is as high as 1 per cent the limit of most cultivated plants is reached. Further concentration kills all our ordinary agricultural plants. This is at once understood when the osmotic properties of the salts in root-cell solutions are considered. Dyer found that the acidity of root saps of a number of our common agricultural plants was equivalent in concentration to a 1 per cent solution of citric acid. The osmotic pressure in 1 per cent citric acid solution is roughly the same osmotic pressure of the 1 per cent solution of the soluble matter in the alkali soil at Billings, Mont.; so if the concentration of the soil solutions becomes greater than a 1 per cent solution the osmotic pressure of the solution outside of the cell is greater than the pressure of the solution inside the cell and the cell is unable to absorb water, the plant turns yellow, just as it would do if the soil contained too little moisture, and finally dies. This is but a rough comparison for illustration purposes only, for it is not to be supposed that the soluble matters of the root cell are all acids and acid salts. There are, unquestionably, neutral salts present which influence osmotic pressure. The real osmotic pressure in the root cells is so difficult a matter to determine that relative value only can thus be very roughly approximated for the osmotic pressure inside the cell and in the soil moisture in the alkali lands at Billings.

Hilgard states that plants will stand a larger percentage of sodium sulphate than of sodium chloride. The reason is that for the same concentration, expressed in per cents, the osmotic pressure of the sodium chloride is greater than the osmotic pressure of the sodium sulphate. Consequently a plant is able to bear more of the sulphate than of the chloride.

Some of our agricultural plants show a greater ability to stand salts in solution than others. The reason for this is probably explained by the fact that in some plants the concentration of the cell solution is greater than in other plants. The osmotic pressure of the sugar-beet root cells, for example, may be greater than those of other plants, and for that reason the beet can grow when the soil solutions are of higher osmotic pressure.

It has been found that the solid grains of soil have the remarkable power of absorbing or concentrating a portion of the salts on their surface and thus withdrawing them from active solution. This is of the greatest practical importance, as otherwise the soil moisture would quickly become saturated with salts and rendered totally unfit for agricultural plants. As a matter of fact, in consequence of this condensing power, in no case was the concentration of the soil moisture found to exceed 3 per cent, although the salts were quite soluble and were crystallized out on the surface of the ground.

The amount of soluble salts which plants can stand depends upon the character of the salt, the character of the soil, and the kind of plant. Hilgard states that few plants can bear as much as 0.1 of 1 per cent of sodium carbonate, or about 3,500 pounds per acre to a depth of 1 foot; of sodium chloride, about 0.25 per cent, and of sodium sulphate most plants can grow with 0.45 to 0.50 per cent present, and are affected by even less salts in the sandy lands than on heavy clay or gumbo lands.

The soluble salts at Billings, Mont., are mainly sodium sulphate and magnesium sulphate, with none of the sodium carbonate and with but a trace of sodium chloride. The soils also contain a considerable amount of the difficultly soluble calcium sulphate or gypsum.

The following table gives the mean of five analyses of the soluble salts by Dr. F. W. Traphagen, of the Montana Station. From his researches the composition of the salts appears to be very constant throughout the valley.

Composition of the soluble salts at Billings, Mont.

	Per cent.
Sodium sulphate	57.44
Magnesium sulphate	27.59
Calcium sulphate	13.05
Potash sulphate	1.55
Silica	.36
	99.99

The sodium sulphate and the magnesium sulphate accumulate to such an extent in the draws and low levels that all agricultural crops

A NEAR VIEW OF THE SANDSTONE BLUFF ON NORTH SIDE OF VALLEY.

are destroyed and the land abandoned. The important question at once arises as to the origin of these salts, what they have been derived from, how they were distributed in the soils before the practice of irrigation had been introduced, and how they leach and shift about in the soil as a result of overirrigation.

It is so important that a clear conception be obtained of this subject that a short space will be given to a consideration of the formation of soils and to the cause of the accumulation of such large amounts of soluble salts in the soils of the arid regions.

THE FORMATION OF SOILS.

Soils are derived from the disintegration and decomposition of rocks. It is unnecessary to speak here of the influences which occasion this decay, but it is sufficient to say that the process of the breaking down of rocks and the formation of soils is taking place with varying rapidity at every point where rocks are exposed to the action of the weathering influences.

During the weathering process the rock crumbles and breaks down into the minute particles composing the resultant soil. While the rock itself had been hard and continuous, with little appreciable space for the absorption of water and air, the resultant soil is permeated with air spaces aggregating about 50 per cent of the bulk of the soil. As one of us pointed out years ago, in the formation of the soil at least half of the bulk of the rock has been leached out and carried away, or else the material of which the rock was composed has swollen to twice the superficial volume it originally occupied. Chemical investigation has shown, however, that a very large percentage of the original rock material is actually dissolved and carried off.

The following table, compiled from the writings of G. P. Merrill, will give a general idea of the magnitude of the changes due to the solubility of the rock in the formation of soils and will give an idea of the enormous amount of material that must be decomposed and removed in order to form soil one foot in depth on an acre of land:

Amount of soluble matter removed in the decomposition of rocks and the formation of soils.

Kind of rock.	Locality.	Rock removed by solution for each acre-foot of soil formed.	
		Per cent.	Tons.
Granite	District of Columbia	13	261
Gneiss	Virginia	45	1,431
Syenite	Arkansas	56	2,227
Phonolite	Bohemia	10	195
Diabase	Massachusetts	15	309
Diabase	Venezuela	40	1,166
Basalt	Bohemia	44	1,376
Basalt	France	60	2,625
Diorite	Virginia	38	1,072
Soapstone	Maryland	52	1,895
Soapstone	Virginia	78	6,204
Argillite	Maryland	41	1,216
Limestone	Arkansas	98	85,760

During the weathering process, therefore, and especially in the slow decomposition of the minerals of the rock or soil, certain portions, and in the aggregate very large portions, of the rock are rendered soluble and accumulate within the soil as soluble salts, or are carried off in solution and washed off into the ocean or some inclosed basin which receives the drainage waters of the district. Through the action of water alone, or through the action of water containing minute quantities of carbonic or other organic acids, rocks of all kinds are thus slowly dissolved. In the humid portions of the United States approximately 50 per cent of the rainfall seeps down through the subsoil and runs off through the rivers into the ocean. This constant seepage through the soil prevents any excessive accumulation of soluble matters within the soil. In the arid portions of the country, however, under scanty rainfall there is not sufficient underdrainage or seepage waters to carry oft the amount of salts rendered soluble in the decay of rocks, and we have, therefore, as a rule, a much larger soluble salt content in soils of the arid regions than in the soils of the humid regions. The greatest contrast is of course shown in the case of the very soluble salts of sodium, magnesium, calcium, and potassium. These are very completely removed from the soils of the humid regions. The very fact of the easy solubility of the salts renders them dangerous in the practice of agriculture when they accumulate, as in the soils of the arid West.

The kind of salt depends, of course, upon the kind of rock, and to a certain extent upon the factors producing decomposition.

The following table gives a list of the alkali-bearing minerals occurring in primary rocks as the ultimate source of the alkali of soils:

Feldspars:	Per cent of alkalies.	Micas:	Per cent of alkalies.
Orthoclase	17	Muscovite	12
Microcline	17	Biotite	10
Albite	12	Phlogopite	9
Oligoclase	9	Nepheline	24
Andesite	8	Leucite	21.5
Labradorite	4	Sodalite	26
Bytownite	3.5	Hauyn	17
Anorthite	2		

Some of these alkali-bearing minerals are very generally present in the primary rocks from which the soils have all ultimately been derived, but they are of course usually mixed with other minerals, so that the total percentage of alkalies in the rock are not so great as would appear from these minerals.

In the formation of sedimentary rocks these soluble salts are often deposited in local areas to such an extent as to form a marked feature of the subsequent geological formation of the land. Where the sedimentary rocks are formed in inclosed basins the soluble salts which have leached out of the soils in the decomposition of the rocks over the drainage area are concentrated by the evaporation of the waters of the inland lake or sea and the salts are precipitated out of solution and deposited in layers, either in a pure state or mixed with the sedimentary material that is brought down with them. Such a concentration and precipitation of salts is seen in the Great Salt Lake district of Utah, in the Dead Sea, and in the many salt lakes of central Asia. To a modified and limited extent the same accumulation goes on in the salt marshes along the coast.

The water of the ocean at the present time contains about 3½ per cent of soluble salts, having the following composition:

Composition of the dissolved salts of sea water.

	Per cent.
Sodium chloride	78
Magnesium chloride	11
Magnesium sulphate	5
Calcium sulphate (gypsum)	4
Potassium sulphate	2

Of these salts the calcium sulphate or gypsum is very slightly soluble, and on concentration of the solution this is the first salt to be deposited. The soils of the arid West are particularly rich in gypsum and carbonate of lime, and there are many extensive deposits of gypsum in beds, which are capable of being worked commercially. Such depositions from the evaporation of vast bodies of water are believed to be the origin of extensive deposits of gypsum. If the concentration continues sufficiently long the sodium chloride and the sulphates are deposited. In the salt mines at Stassfurt, Germany, the rock salt, which was formerly the substance of principal value to be mined, was overlaid with sulphates of soda, magnesia, and potash, and chlorides of potash and magnesia, while the rock salt was underlaid with very deep deposits of calcium sulphate or gypsum. There are many places in the West where the salts have deposited and where they are now depositing, mixed with large quantities of sedimentary materials and not in pure deposits of salts. In later geological ages, when these sedimentary rocks are raised to the surface and again subjected to erosion, the salts are again exposed to the solvent action of meteoric waters.

In humid regions the salts are removed by leaching almost as rapidly as the disintegration of the rocks proceeds, and there is little evidence in the soil of their former existence. However, in wells driven to the lower depths of the subsoil, where the movement of the water has been slow and the soluble salts have been only slowly and partially removed, the water is frequently charged with the soluble mineral salts. Deep-seated springs also very frequently give evidence of soluble mineral matters within the depths of the rocks, as seen in the many mineral springs in all sections of the country.

Where the rainfall is slight, as in the arid regions, and the leaching of the salt and the underlying rocks is small, the removal of the soluble matter has not gone on to such a degree. Immediately below the surface there are evidences of their presence, and in localities of very small rainfall and very scant drainage, and where the evaporation of the soil moisture has been excessive, the salts often appear as efflorescence on the surface of the ground.

The nature of the rock gives some indications of the relative amount of alkali to be found in it, as a greater amount of salts is deposited in the slow-forming shales than in the more rapid formation of the sandstone rocks. The source of the alkali salts at Billings is in the shales forming the bluffs on the south side of the valley, rather than in the sandstone of the north bluff.

The mineral elements occurring as "alkalies" in the arid regions the world over consist mainly of sodium, magnesium, and potassium, combined as carbonates, chlorides, sulphates, and occasionally as nitrates, phosphates, and borates. The alkalies themselves are derived originally from the decomposition of the feldspars and micas and three or four other minerals mentioned in the list on page 12.

The origin of the carbonic acid of the carbonates is either the atmosphere or decaying vegetation. The water percolating through the soil is charged more or less with carbon dioxide and the solubility of the rocks is very much greater in these carbonated waters than in pure water. The most important factor in rock decomposition, especially in deep-seated rocks, is the hydration—that is, the chemical combination of water with the minerals forming the rock. This action finally results in the liberation of the alkalies as carbonates and the formation of free silica and the simple silicates of alumina, magnesia, etc. The complete kaolinization of one of the feldspars indicates the processes of the formation of alkaline carbonates in the decomposition of alkali-bearing minerals.

The following equation represents the full and complete decomposition of feldspar and the formation of kaolinite and free silicic acid and potassium carbonate:

$$\underset{(Orthoclase)}{2K_3Al_3Si_9O_{24}} + \underset{(Water)}{6H_2O} + \underset{(Carbonic\ acid)}{3CO_2} = \underset{(Kaolinite)}{3H_4Al_2Si_2O_9} + \underset{(Silica)}{12SiO_2} + \underset{(Potassium\ carbonate)}{3K_2CO_3}$$

There are, of course, many stages before the complete decomposition of the feldspar, and more complex reactions probably occur during the process, but the final products are indicated in the general changes noted by the equation, and this is the prime source of the alkaline carbonates.

The source of the sulphuric acid, which is in combination in the sodium sulphate of our alkaline plains and in combination in calcium sulphate or gypsum, is probably the oxidation of free sulphur in and around volcanic districts in the alteration of pyrite and marcasite, and in the subsequent deposition of sulphates from sea water.

Maxwell, in writing upon the Hawaiian lavas and soils, notes the occurrence of steam and water vapor containing 5 per cent of free sulphuric acid. Such acid waters coming in contact with the rocks dissolve the lime, magnesia, alumina, iron, and the alkalies with the formation of gypsum, magnesium sulphate, iron sulphates, alkali sulphates, and

A VIEW OF THE SANDSTONE BLUFF, WITH AN ALKALINE STREAM IN THE FOREGROUND DOING ITS SHARE IN CARRYING OFF THE EXCESS OF SOLUBLE SALTS.

several alums. The sulphates of iron thus formed readily decompose in the presence of water, forming oxides of iron, other forms of sulphate, and even free sulphuric acid. The sulphates and free sulphuric acid in contact with lime or alkali carbonates react with the formation of lime or alkali sulphates and iron carbonates or oxides, so that in the presence of pyrites or marcasite the lime or alkaline carbonates will be changed, to a certain extent at any rate, into sulphates.

There are other reactions equally important to the agriculturist besides those which have just been noted.

Hilgard has repeatedly called attention to the reactions between lime salts and the salts of the alkalies.

Where sodium or potassium carbonates or chlorides are associated with calcium sulphate in a well-aerated soil, a reaction takes place in which sodium or potassium sulphate and calcium chloride or carbonate are formed. The calcium chloride is extremely soluble and easily leached from the soil if there is any chance at all of its being carried off by drainage waters. The calcium carbonate is difficultly soluble and would remain in the soil as limestone. On the other hand, where sodium or potassium sulphate exists in the soil, together with lime carbonate and in the presence of an excess of carbonic acid or in the presence of supercarbonates of the alkalies, the reverse action takes place and carbonate of soda or potash is formed, together with the sulphate of lime.

Hilgard shows this reaction actually taking place in certain conditions of the soil. He points out that the carbonate of soda and sulphate of lime may occur in the bottom of a slight depression, where the soil is moist, while the sodium sulphate and calcium carbonate will be found around the edges where the soil is better drained. As a practical application of this matter, he urges the use of gypsum or sulphate of lime in the reclaiming of lands containing the black alkali or carbonate of soda, and at the same time points out the necessity of thorough drainage in connection with the application of gypsum; otherwise the application will do no good at all.

These various reactions and properties of the so-called alkali salts indicate the methods for the reclamation of the alkali lands. In the case of the carbonates the course recommended by Hilgard is unquestionably the proper one—to treat the soil with heavy applications of gypsum and insure thorough drainage, so as to have the soil well aerated. In the case of an excess of sodium chloride, which is very soluble and easily leached out of a soil, it is only necessary to flood the soil and remove the excess of salt in this way. It is essential, however, that the soil so treated should have good underdrainage in order that the water applied at the surface may percolate through and actually carry off the excessive amount of the soluble sodium chloride. No application of any kind will be beneficial, as the sodium chloride is as simple a salt as one can have and quite harmless, except when present in extraordinary amounts.

The treatment of soils containing sodium sulphate is more difficult than in the case of the chloride, as the salt is less easily leached from the soil. Here again no application, however, can be made, the sulphate, like the chloride, being injurious only when in large excess. It will be shown further on that the surest plan in the cultivation of these alkali soils is to use care in applying the water, so that there shall be no accumulation of the salts at the surface, and, as Hilgard has repeatedly recommended, the cultivation should be very thorough so as to prevent, so far as possible, the evaporation of the water from the surface of the ground. When the salts have once accumulated, however, there is nothing to do but wait for them to gradually leach away through the drainage and seepage waters or to thoroughly underdrain the land with tile drains, and so hasten the reclamation.

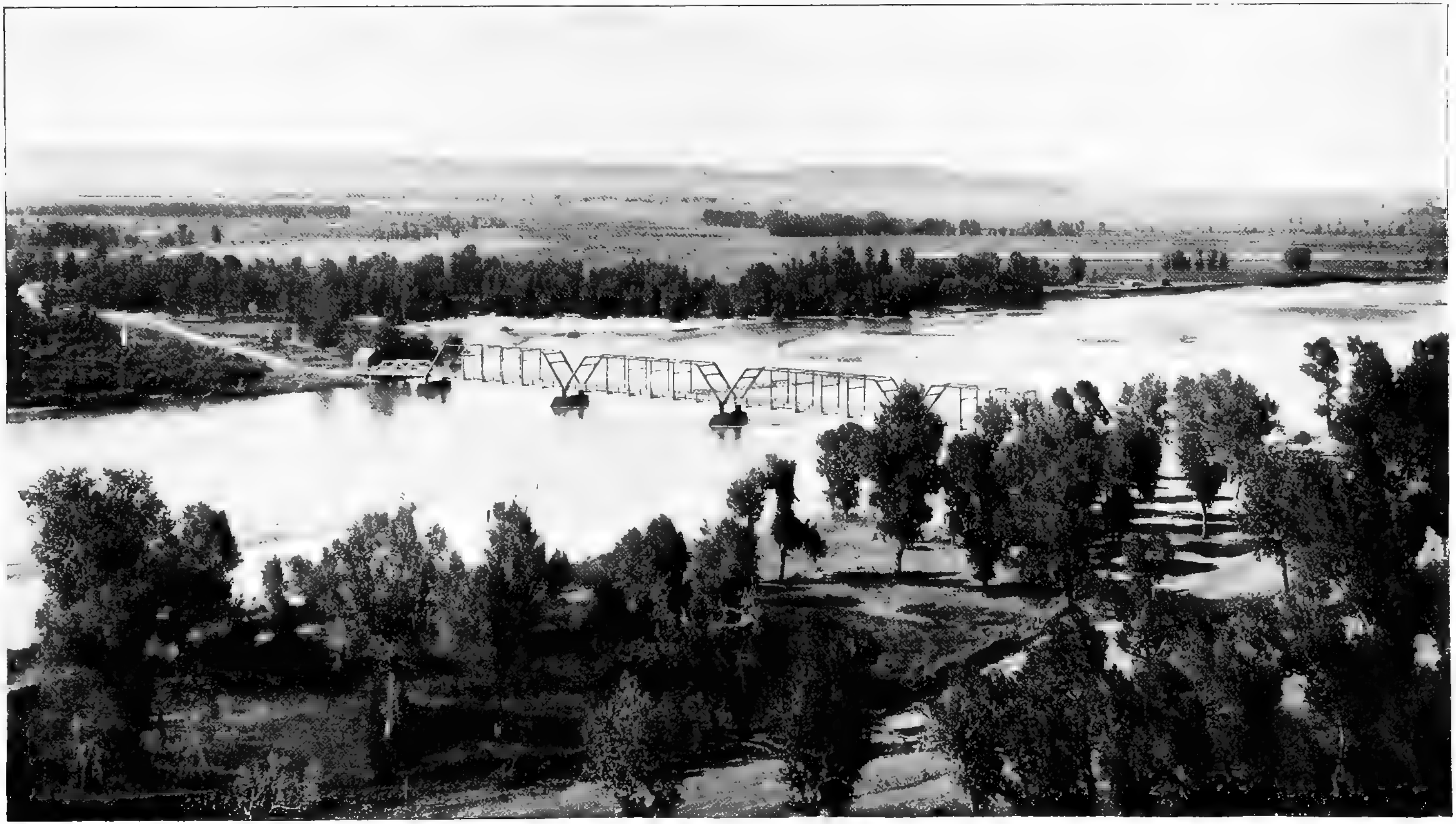
THE GEOLOGICAL STRUCTURE OF THE VALLEY AT BILLINGS.

The Yellowstone River at Billings traverses a broad valley from 6 to 10 miles wide. A sketch map (fig. 1) is given of a portion of the eastern part of the valley, showing the relative positions of the irrigating ditch, the river, the site of Billings, and the bluffs on either side. The valley is bordered on either side with high bluffs. On the north side the bluff is of sandstone. On the south are steep ragged hills of blue shale. The shale or slate dips under the sandstone and is found at various depths throughout the valley.

Fig. 2 gives a diagrammatic illustration of the relative positions of these two classes of rocks. The section is drawn from north to south across the valley.

The sandstone is a gray siliceous stone, rising abruptly to a height of from 200 to 500 feet above the general level of the valley. The rocks are of the Upper Cretaceous age included in the great series of cretaceous rocks extending over the greater part of eastern Montana. The sandstone forms an excellent building stone if protected from the alkaline waters of the locality, but under the influence of these salts the stone breaks down and crumbles into loose sand. The sand grains in the rock are about 0.5 to 0.1 millimeter in diameter, and water readily penetrates the pores of the stone. Small but perceptible quantities of magnesium and sodium sulphates are to be found throughout the sandstone rocks, and where evaporation has gone on from the surface for a considerable time white crusts of these salts form on the surface.

Water seems to percolate through fine veins and cracks in the rocks and issue at the sides and the foot of the bluffs, in many places giving rise to springs of alkali water containing a greater or less amount of the soluble sulphates. Wherever this water issues, the rock disintegration has gone on to a great extent, and grottoes are formed in this way in the bluff. There are frequently hard compact layers throughout the rock, and the soluble salts accumulate just above these and are seen on the surface in the canyons and exposed bluffs as white efflorescence or layers lying parallel to the layers of hard and impervious material.



GENERAL VIEW OF THE VALLEY LOOKING TOWARD THE TOWN OF BILLINGS, SHOWING THE CHARACTER OF THE BOTTOM LANDS AND THE DRAINAGE FROM THE VALLEY.

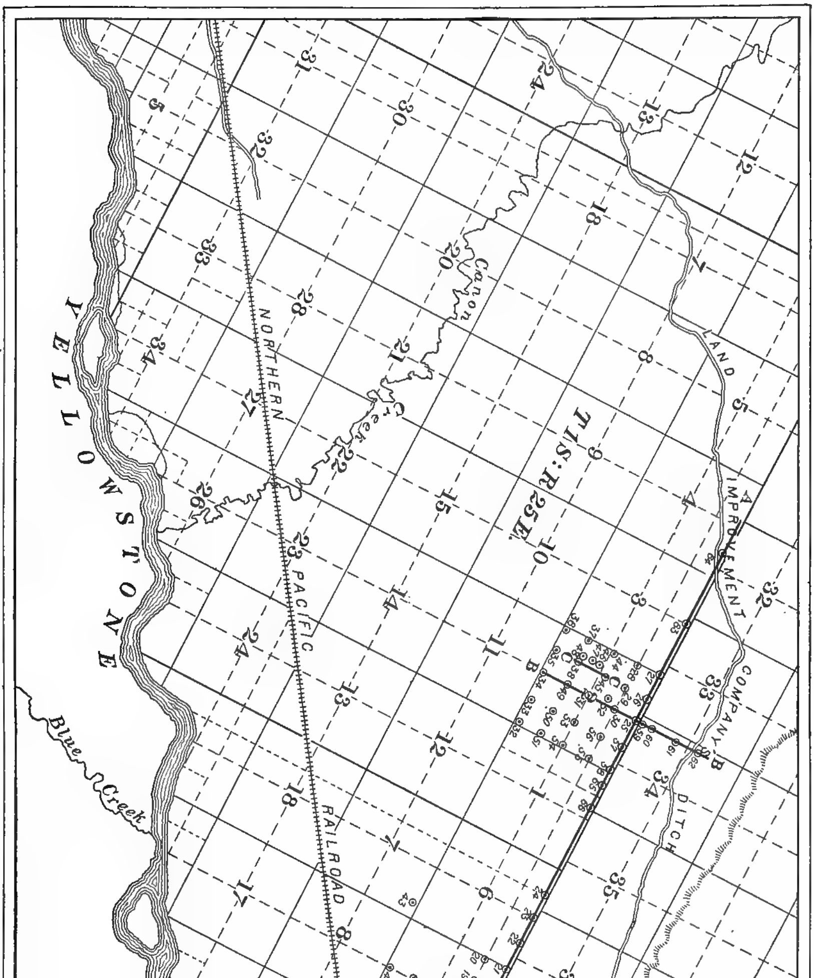


FIG. 1.—Sketch map of a portion of the Yellowstone Valley near Billings, Mont, showing the area examined and the location of the borings.

The main body of the sandstone has been eroded rather unevenly and the peculiar pinnacle-shaped structure is seen that is so characteristic of the Bad Lands. The face of the bluff, however, is completely rounded by weathering, and the general ragged character is smoothed off by the continual falling of the débris, due to the rapid disintegration of the rock when freely exposed to the weathering influences.

Underlying the sandstone and coming out from under the sandstone bluff there is a fine blue shale or slate which extends to an unknown depth. In an attempt to get artesian water at Billings a well was driven 900 feet through this shale. No deeper record than this has ever been made at this place. The shale rises up from beneath the sandstone and forms the rough angular blue hills on the south side of the valley.

The shale is penetrated with numerous fine cracks and joints running in all directions, and these are filled with fibrous gypsum. Many cavities also are found filled with gypsum and calcium carbonate. Everywhere throughout the shale large quantities of sodium and magnesium sulphates are found, which appear as white efflorescence where evaporation has taken place. These blue shales were deposited in the saline

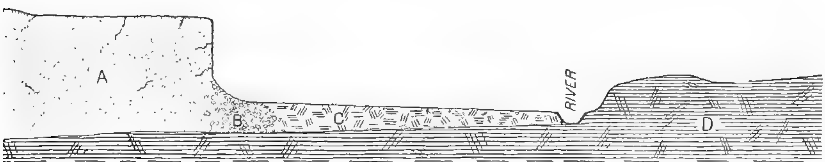


Fig. 2.—Geologic structure of the Yellowstone Valley at Billings.

waters of an inland basin where lime, sodium, and magnesium salts were deposited in large quantities. If there were any alkaline carbonates or chlorides present at that time chemical reactions have taken place and the carbonates and chlorides have been changed or entirely removed from the soil, as there is little or no trace of these present except in the form of carbonate of lime. The vast quantity of carbonate of lime present indicates the possibility of the previous existence of sodium carbonate in some quantity, but if it did exist there has been a reaction between the gypsum and the sodium carbonate whereby calcium carbonate and sodium sulphate have been formed, as there is but a trace of sodium carbonate in the rocks or in the soils of the valley.

A number of illustrations (Pls. II, III, IV, and V) are given showing in general and in detail the character of the sandstone and shale bluffs which border the valley and from which the soils of the valley have been derived. The legends on the illustrations will show quite plainly the object which they are intended to represent.

The weathering of these two rocks has given rise to the soils of the valley. From what has previously been said it will be seen that the rocks themselves are the present source of the soluble salts in the valley. As the rocks weather, a portion of the soluble salts is removed in the springs and seepage waters, but the removal is not nearly so complete as is the case in the humid portion of the United States, because the small rainfall renders the escape of all of the excessive amounts of salts impossible.

The two types of rock give rise to two distinct types of soil in the valley—one a sandy soil, derived from the disintegration of the sandstone rock, giving a soil of open texture easily worked, in which there is less trouble from alkali on account of the more perfect drainage and less risk of the accumulation of seepage waters; the other type is a stiff clay or gumbo formed from the disintegration of the shales. These shale soils are extremely fertile when in good condition, but are quite difficult to work. They are easily puddled and are rendered almost impervious to water by the excess of the soluble salts which they usually contain, and it is upon these soils, with their poor underdrainage, that the greatest amount of trouble has arisen from the accumulation of seepage waters and salts in the overirrigation of the soils in the valley.

Between these two extremes of sandy soil and gumbo, in areas where the layer of sandstone has not been completely removed, the soils are blended in all possible combinations, from the pure type of the sandy soil to that of the gumbo.

The following table gives the mechanical analyses of a number of soils from Billings, which indicate the difference in the texture of the soils which has been noticed.

Mechanical analyses of soils.

No.	Locality. (Miles from Billings.)	Description.	Moisture in air-dry sample.	Organic matter.	Gravel. (2 to 1 mm.)	Coarse sand. (1 to 0.5 mm.)	Medium sand. (0.5 to 0.25 mm.)	Fine sand. (0.25 to 0.1 mm.)	Very fine sand. (0.1 to 0.05 mm.)	Silt. (0.05 to 0.01 mm.)	Fine silt. (0.01 to 0.005 mm.)	Clay. (0.005 to 0.0001 mm.)
			P. ct.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*
3756	2½ N	Sandstone bluff soil.	1.22	2.66	0.00	0.00	0.17	29.39	52.34	3.29	0.88	9.65
3322	11 W	Silty type, creek soil.	2.98	4.40	0.00	0.00	0.16	7.96	28.79	34.45	4.67	17.25
3309	5½ W	Sandy gumbo	1.56	4.66	0.00	0.00	0.20	11.72	45.05	14.69	3.49	19.90
3308	5½ W	do	1.94	3.30	0.00	0.10	0.46	15.61	39.59	14.63	3.38	21.30
3307	5½ W	do	2.35	3.72	0.00	0.02	0.32	21.37	38.27	8.99	3.13	22.55
3306	3 W	Gumbo	3.20	3.30	0.01	0.40	1.58	20.40	27.67	11.71	4.02	27.30
3769	5 W	Heavy gumbo	3.74	4.22	0.04	0.03	0.19	11.65	24.03	15.13	4.40	35.55

The first sample is a very pure type of sandstone soil taken from the top of the bluff about 2½ miles north of Billings and was derived from the decomposition of the soft layers of fine sandstone which cap the bluffs. These soils are very light and loose and have very free underdrainage. As a matter of fact, they leach readily, and, although they afford the best possible conditions for irrigation in that seepage waters are not likely to accumulate in them, it is probable that they would not last very long, as the soluble salts would easily and quickly be removed from them. Soils of this type are found in many parts of the valley, and there is little or no danger from seepage waters or from an accumulation of soluble salts at the surface, although they contain considerable quantities of such salts at depths below the surface.

The other samples in the table are seen to grade up through the mixed sandy gumbo to the pure form of gumbo with from 27 to 35 per cent of clay. The mixed soils are the most abundant in the valley.

METHOD OF DETERMINING THE SOLUBLE SALT CONTENT OF SOILS.

The electrical method of determining the soluble salt content of soils has been described in Bulletins 8 and 12 of this division. Briefly, the method consists in taking a sample of soil with an auger at any desired depth in the field, adding sufficient distilled water to thoroughly saturate it and bring it into the condition of a thick paste. This is then filled into a hard rubber cell with metal electrodes, and the electrical resistance of the saturated soil determined with a modification of the apparatus described in Bulletin No. 8, a full description of which will be published at a subsequent time.

The resistance so found can be taken as the resistance of a salt solution filled with inert grains of soil. The effect of the soil grains is to increase the resistance about 100 per cent. This effect is constant for all ordinary soils. The resistance of the soil moisture can be calculated by multiplying the resistance of the cell by this factor and reducing for temperature, which has previously been determined. This will give the resistance of an amount of salt solution equal to that in the cell and without the presence of the soil. The specific resistance of this solution can then be determined, and by comparing this with the specific resistance of solutions of different strength of sodium chloride or of any other salt, the actual amount of salt can be determined in terms of the salt used as a basis for comparison. In this investigation the actual composition of the alkali, as determined by Dr. Traphagen, was taken as the basis of calculation, and all of the results have been worked out in terms of this analysis, which is given on page 10.

Plate VI shows the complete outfit for the determination of the soluble-salt content of soils as actually used in the field. The sample is taken with the auger, mixed in the field in a porcelain dish with distilled water, filled into a hard-rubber cell, and the resistance is then taken. The temperature of the soil in the cell is taken. The calculations can be made there or at any subsequent time. If the amount of moisture added is once actually determined, the variations in the amount added in different experiments have very little value. The moisture determinations do not, therefore, have to be made in each case.

This method is extremely sensitive and is very rapid. The determinations can be made by one man quite as fast as the samples can be drawn by another, and much faster if the ground is hard and dry.

FIELD APPARATUS USED IN SALT DETERMINATIONS.

Where the character of the soils vary considerably throughout the region or at different depths, it would require, of course, frequent chemical analyses to give a basis for the calculations; but over the area examined at Billings Dr. Traphagen had already shown that the alkali was very uniform in its composition, and no such frequent examinations were considered necessary.

PLAN FOR THE INVESTIGATION.

The objects of the investigations may be briefly stated. It was important to know the amount of soluble salts in the principal types of soil, which had been kept under approximately the same conditions as to exposure, cropping, and irrigation. It was important to determine the amount and distribution of the salts above the ditch where the land had never been irrigated and in the irrigated districts, and it was furthermore important to study the distribution of the salts in soils which had been or were now being ruined by the presence of alkali.

To carry out this plan three lines of borings were run—one of 5 miles in length and the others, for more detailed study, of about 1½ miles and one-fourth mile, respectively, in length. The longer section began above the ditch and went down toward the river; the others extended from an alkali flat and from a drainage ditch back into the higher levels. The position of these sections is shown on the sketch map of the valley. In each of these sections a number of borings were made and the salt content determined at every foot in depth down to 10 or, frequently, 15 feet. These borings were all numbered and their position accurately marked on the working maps. In addition to this, a section or square mile of land was studied in great detail and borings were made at frequent intervals to a depth of 10 or 15 feet. A number of special borings were also made to study the relation of the different types of soil to the amount and distribution of the salts.

The results of the investigations have been illustrated in the accompanying diagrams.

One set of the diagrams (Pls. VII, VIII, and IX) illustrates graphically the salt content of the soils found in the sections that were run; other charts (Pls. X, XI, XII, and XIII) show graphically the depth to standing water and the amount and distribution of salt for several depths in the section of land which was plotted. This gives an underground map showing the depth to standing water and the distribution of the alkali salts at several levels below the surface. Such a map is invaluable for the thorough understanding of the conditions under the soil with which the planters have to deal. If danger threatens, it shows the direction from which it is to come; where the land has already been injured, it shows exactly what the conditions are and where the cause is located. Furthermore, the method of salt determination is so sensitive and so rapid that inquiries of this kind can be readily extended over large areas with comparatively little expense.

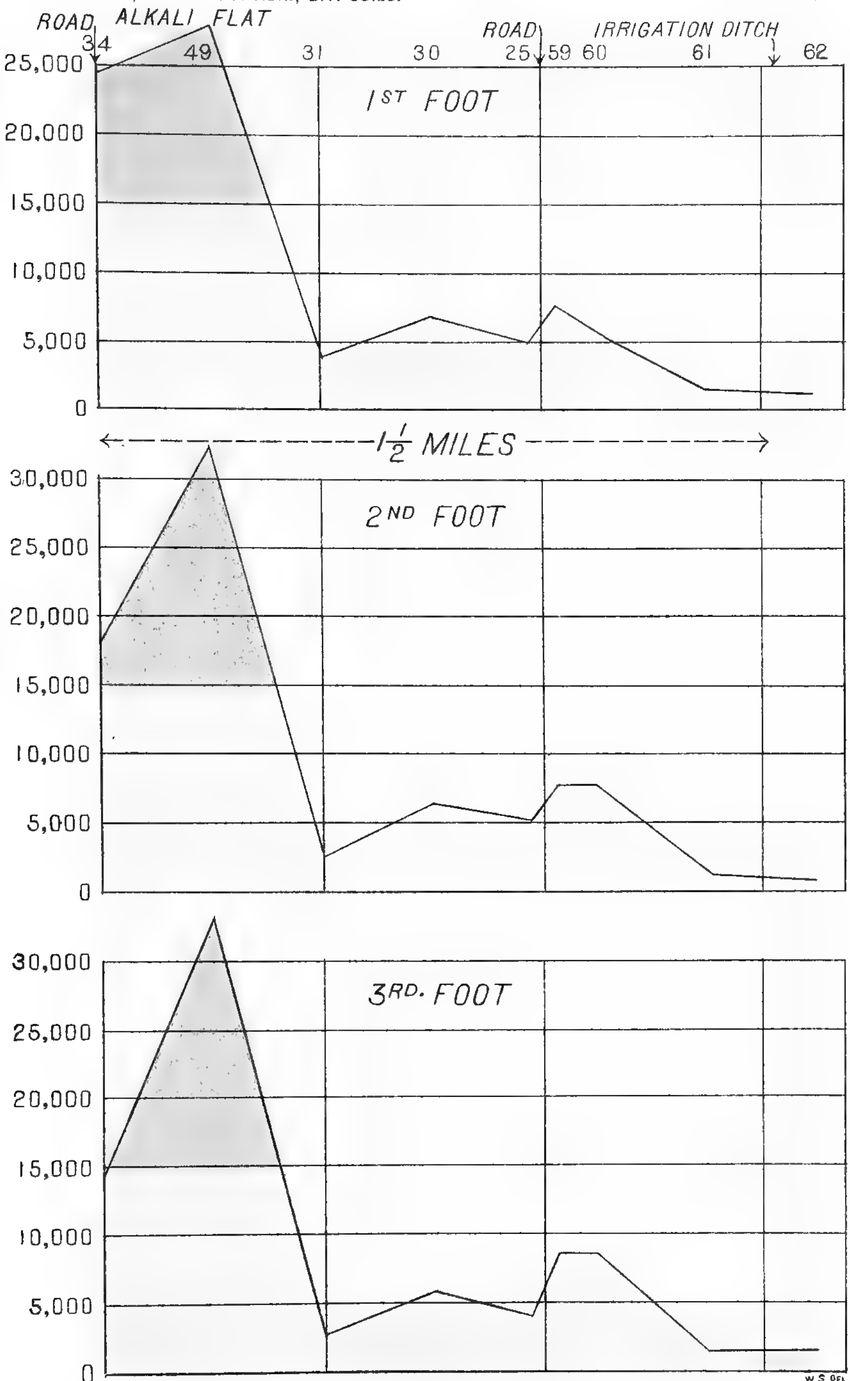
As a result of the investigations at Billings it was found that plants could just exist with 0.45 of 1 per cent of the soluble salts present, equivalent to about 15,000 pounds per acre-foot, and this is taken as the limit of plant production. The soluble salt content of soils in the humid portion of the United States ranges from 50 pounds per acre-foot in the sandy soils of the Atlantic coast to as much as 3,000 or 4,000 pounds in some of the heavier agricultural soils. The average amount would be considerably less than 1,000 pounds per acre-foot.

THE RAINFALL AND SEEPAGE.

There are no available records of the amount of rainfall at Billings, but at Miles City the Weather Bureau records show an average annual rainfall of 12.8 inches. From May to September, inclusive, there are 6.7 inches, and during July and August 1.3 inches.

Plate XIV shows a section of the soil at Billings from a cañon just below the ditch. The whole depth of the face of the exposed soil is about 20 feet. About halfway down, or at a depth of 10 feet from the surface, there appears to be a layer of water-bearing sand and gravel through which a continuous slow seepage of water takes place. This probably came from the canal, which was perhaps one-fourth of a mile away. Above this point the soil appears to be quite dry. In September, 1897, when this photograph was taken and the water was actually running, a boring was made about a mile above the ditch. The upper soil appeared to be air-dry, but about 3 feet below the surface the soil was perceptibly moist, although there had been no rain for three or four months at that time. It was stated that standing water could be found at this place at a depth of 20 or 30 feet below the surface, which would correspond with the depth of the strata from which the water was running in the cañon below the ditch. We have then the problem of a desert with standing water at a depth of from 20 to 30 feet from the surface overlaid with 20 feet of almost air-dry compact earth and with only 12 inches of annual rainfall which appears to be insufficient to soak down to this strata.

When the rains occur in the spring and wet the surface of the ranges, vegetation flourishes in the most luxuriant way and the grasses give very good grazing. The rains, however, appear to be only sufficient to wet the surface to a very slight depth, and the water is quickly used up, and true desert conditions prevail during the summer time. From all the evidence it does not seem probable that the rainfall reaches down into the water-bearing strata to any great extent. It is not probable that the water-bearing strata is supplied from the local rainfall. It appears that in the dry season the soil is moist from 3 feet down, but so slightly moist and the depth of the dry material is so thick that it is altogether unlikely that the spring rains pass down to any appreciable extent locally in any one year. The conditions, therefore, are unfavorable to a natural leaching of these soluble salts except through the exceedingly slow movement there may be in the slightly moist subsoil.



SECTION B. THROUGH BORINGS 34 TO 62.

SALT CONTENT FROM A LINE OF BORINGS ONE AND A HALF MILES OUT FROM AN ALKALI FLAT. THE BLUE COLOR INDICATES THE EXCESS OF SOLUBLE SALTS.

SALT CONTENT OF THE SOIL.

An investigation was made of the salt content of a marked type of the sandy soil from above the ditch upon which water had never been applied through methods of irrigation.

The following table shows the amount and distribution of the salts in two places:

Amount of soluble salt in sandy soil.

UNIRRIGATED.

Depth (feet).	Boring 62.		Boring 64.	
	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.
0- 1	0.033	1,155	0.042	1,470
1- 2	.019	665	.041	1,435
2- 3	.045	1,575	.035	1,225
3- 4	.027	945	.038	1,330
4- 5	.032	1,120	.045	1,575
5- 6	.028	980	.055	1,925
6- 7	.019	665	.056	1,960
7- 8	....	....	.170	5,950
8- 9	....	....	.238	8,330
9 10	....	....	.243	8,505
10-11	....	....	.205	7,175
11-12	....	....	.120	4,200
12-13	....	....	.163	5,705
13-14	....	....	.228	7,980
14-15	....	....	.178	6,230

It will be seen that there is not sufficient soluble matter down to a depth of 15 feet to prevent the growth of agricultural plants, as the amount does not approach the limit of 0.45 per cent, or 15,000 pounds per acre-foot. It is interesting to note, however, that the amount of soluble salt in the upper 7 feet of the soil is particularly small. There is 50 per cent more, perhaps, than is ordinarily found in the soils of the humid region. Below a depth of 7 feet, however, the amount of salt is considerably increased. It would appear that there were evidences here of a slow downward movement of soil moisture, and that under these constant conditions of slow seepage the amount of salt in the upper layers of the soil was constantly diminishing. No examinations could readily be made of the soil below a depth of 15 feet, as this was the extreme length of the auger, but from information furnished by some well-diggers thoroughly familiar with the locality it was learned that the soluble salt content increases below this to very large proportions. White layers strongly impregnated with salts are said to be found below this depth. The water from the wells contains too much of the salts to be of use for domestic purposes, although it is not so strong as to be harmful to cattle.

It is quite reasonable to suppose that the soluble salts had originally been uniformly distributed throughout the upper layers of these soils, and that from storm waters and the slow seepage of the slight amount of moisture which the subsoil contains the soluble material has been washed down from the upper layers. Certain it is that similar results follow from the first effect of irrigation where there is good underdrainage, as generally prevails in this sandy soil.

Borings were made in the same character of soil below the ditch and only a short distance away. The following table gives the salt determinations in three borings made in this irrigated sandy soil:

Salt determinations in irrigated sandy soil.

Depth (feet).	Boring 26.		Boring 27.		Boring 28.	
	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.
0- 1	0.046	1,610	0.038	1,330	0.033	1,155
1- 2	.049	1,715	.045	1,575	.037	1,295
2- 3	.052	1,820	.044	1,540	.028	980
3- 4	.066	2,310	.051	1,785	.030	1,050
4- 5	.097	3,395	.060	2,100	.048	1,680
5- 6	.106	3,710	.051	1,785	.048	1,680
6- 7	.128	4,480	.064	2,240	.048	1,680
7- 8	.147	5,145	.070	2,450	.047	1,645
8- 9	.112	3,920	.049	1,715	.047	1,645
9-10	.112	3,920	.049	1,715	.047	1,645
10-11	.056	1,960	.072	2,520	.044	1,540
11-12	.056	1,960	.072	2,520	.044	1,540
12-13	.058	2,030	.072	2,520	.044	1,540
13-14	.058	2,030	.072	2,520	.044	1,540
14-15	.058	2,030	.072	2,520	....	....

It will be seen in this case that the amount of soluble matter, even to a depth of 15 feet, is comparatively small, and the amount throughout the whole depth is quite uniform. This indicates very strongly that the salts have been leached out of the soil and carried off in the underground drainage waters. The examination of the water in a well situated in this irrigated area of the sandy land gives additional proof that some of the salts have been removed. There is a well at the southwest corner of section 2, near boring 44, in which the water contains 0.119 per cent of soluble matter, or 60 grains per gallon. Other wells throughout the irrigated area frequently contain as much as 0.4 per cent of salts.

Where this sandy soil is overirrigated, or where from some physical cause the subsoil is compact and the drainage is poor and water accumulates within the subsoil, the seepage waters which move rapidly accumulate and frequently come up to the level of the surface of the ground. Under these conditions excessive evaporation sets in from the surface and salts accumulate until the soil moisture is so saturated that the salts are deposited at the surface as a crust. Such alkali flats are frequently found on the low levels of the Billings area, even in these sandy soils.

The following results indicate conditions in one of these alkali flats, where the sand is underlaid at a slight depth with a heavy gumbo subsoil:

Salt determinations in an alkali flat in the sandy soil.

Depth (feet).	Boring 49.		Boring 52.	
	Per cent of salt.	Pounds per acre-foot.	Per cent of salt.	Pounds per acre-foot.
0–1	0.792	27,720	0.229	8,015
1–2	.920	32,200	.191	6,685
2–3	.944	33,040	.182	6,370
3–4	.792	27,720	.175	6,125
4–5	.519	18,165	.159	5,565
5–6	.519	18,165	.213	7,455
6–7	.357	12,495	....	....
7–8	.357	12,495	....	....
8–9	.292	10,220	....	....

It will be seen that in boring 49, which was in the midst of the alkali flat, there was an excessive accumulation of alkali, beyond the limit of any agricultural plant, at least to a depth of 7 or 8 feet. Below this it rather looks as though the amount of salts was diminishing and that if the boring could have been carried deeper the salt content would perhaps have grown less.

In both these borings standing water was found between 1 and 2 feet of the surface of the ground. Evaporation had been going on for a number of years, the seepage waters being supplied by the overirrigation of lands on higher levels. At the present time the soil in boring 52 does not contain an excessive amount of alkali for the alfalfa, but the level of standing water is so near the surface that the roots of the plants are submerged and the crop can not be successfully grown. This is the first stage in the ruin and devastation that is being wrought, and boring 49 shows the final and complete stage when the land is given up to water and alkali.

When land is in the condition of boring 52, and before any notable accumulation of crust has appeared upon the surface, the land becomes covered with a heavy growth of weeds. All agricultural crops have ceased to grow for some time, and the land has been left out as a barren waste. Such a condition as is shown by the growth of weeds is usually thought to mean that the alkali is disappearing or is being used up by the weeds themselves and that the soil is again becoming fit for crops. In some cases this may be true, if there is sufficient drainage to carry off the excess of seepage waters; but in many cases the conditions simply indicate that the weeds are a class of plants which can thrive on wet ground and grow for a while luxuriantly. If the methods of irrigation are kept up and the seepage waters continue to collect and evaporate for a few years longer, alkali accumulates in sufficient quantities to kill even the growth of weeds, and the land truly presents the appearance of a desert.

Some of the planters are much inclined to accept the prevailing conditions and to look for crops like the Australian salt grass, which will grow in these alkali flats and wet soils. It is wrong to accept these conditions, however, and depend upon these makeshifts, when the conditions ought in the first place to have been prevented and ought now to be removed by radical and energetic methods of drainage or through better and more careful methods of irrigation.

From all the facts thus far observed it can be said that the first harmful effect observed in these sandy soils is caused by an excess of water, and if this is not immediately lessened further damage will result from the accumulation of soluble salts. If the excess of water is soon removed no permanent damage will result.

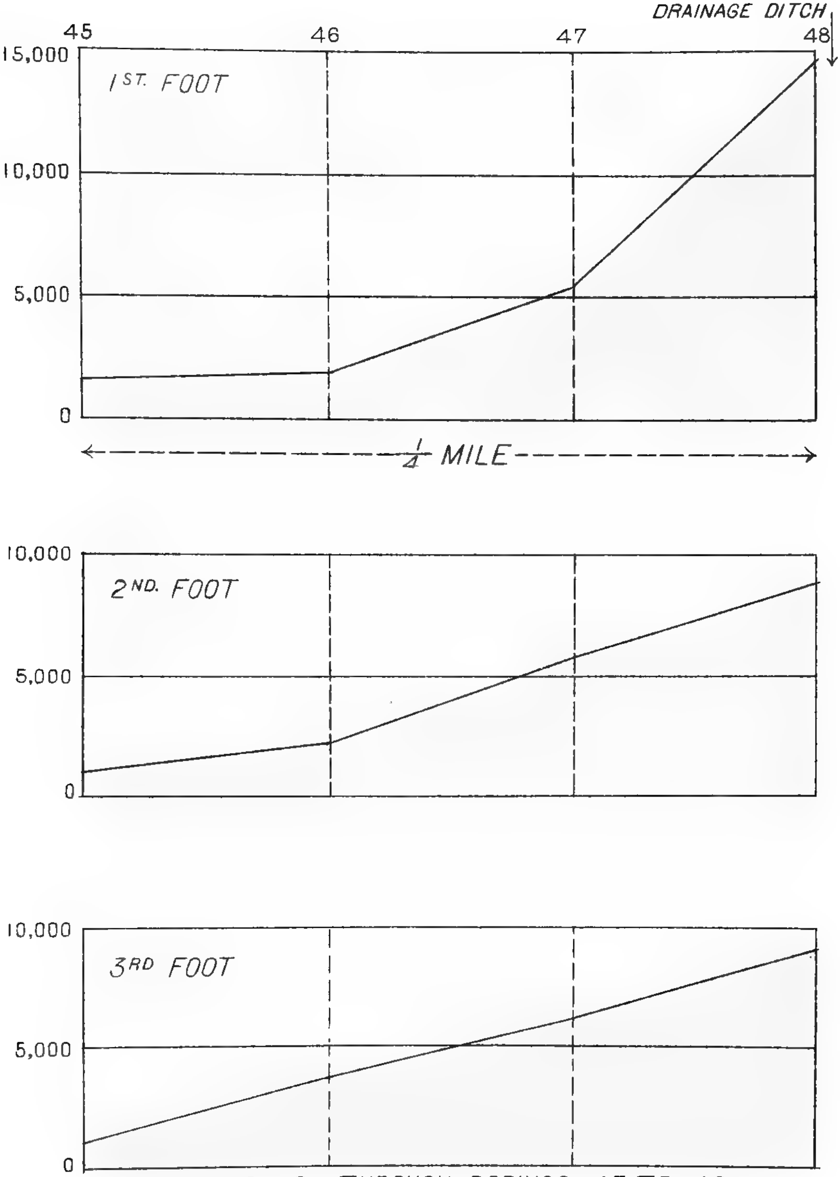
The heavier type of soil—that is, the gumbo soil—was shown to be derived from the disintegration of the shale. The still undecomposed shale in the bluffs on the south side of the valley was found to be penetrated in every direction with veins of gypsum and the soft shale itself to be permeated with large quantities of sodium and magnesium sulphates. The soils resulting from the disintegration of the shale form a heavy, sticky, blue clay quite impervious to water. The drainage is so slow through this fine, impervious material that large quantities of the salts remain in the soil.

On account of the poor drainage and the slow movement of the subsoil waters through this material there is great danger of overirrigation, and the problem of irrigation, which is easy on the well-drained, sandy lands, becomes far more complicated and much more difficult to manage on these heavy gumbo soils. Great care has to be taken, not only in the application of water, but in the actual cultivation of these soils, as they are liable to be ruined for a time at least for alfalfa. On account of the large water content, the fineness of the particles, and the amount of salts these soils contain they easily puddle, and if they are worked when too wet clods form and it is very difficult to reduce the field again to a good tilth.

On account of these properties the heavier or gumbo soils have to be farmed with very great care. Not only so, but there is great danger from seepage waters from neighboring plantations on higher levels. The soils themselves are naturally extremely fertile and very strong and last very well if well cared for. The following table gives the results of salt determinations in typical gumbo soil above the ditch, which has never been irrigated.

The salt content of a heavy unirrigated gumbo soil.

Depth (feet).	Per cent of salt.	Pounds per acre-foot.
0-1	0.035	1,225
1-2	.038	1,330
2-3	.054	1,890
3-4	.200	7,000
4-5	.333	11,655
5-6	.337	11,795
6-7	.253	8,855
7-8	.253	8,855
8-9	.282	9,870



SECTION C THROUGH BORINGS 45 TO 48.

SALT CONTENT FROM A LINE OF BORINGS EXTENDING ONE-QUARTER MILE BACK FROM A SMALL DRAIN IN AN ALKALI FLAT.

It is apparent from the table that there is a considerable quantity of salt at a depth of 5 feet and from there down. This boring, with others, is illustrated graphically in fig. 3.

When water is applied to this gumbo soil in the practice of irrigation, the first effect is to reduce the amount of soluble salts in the upper

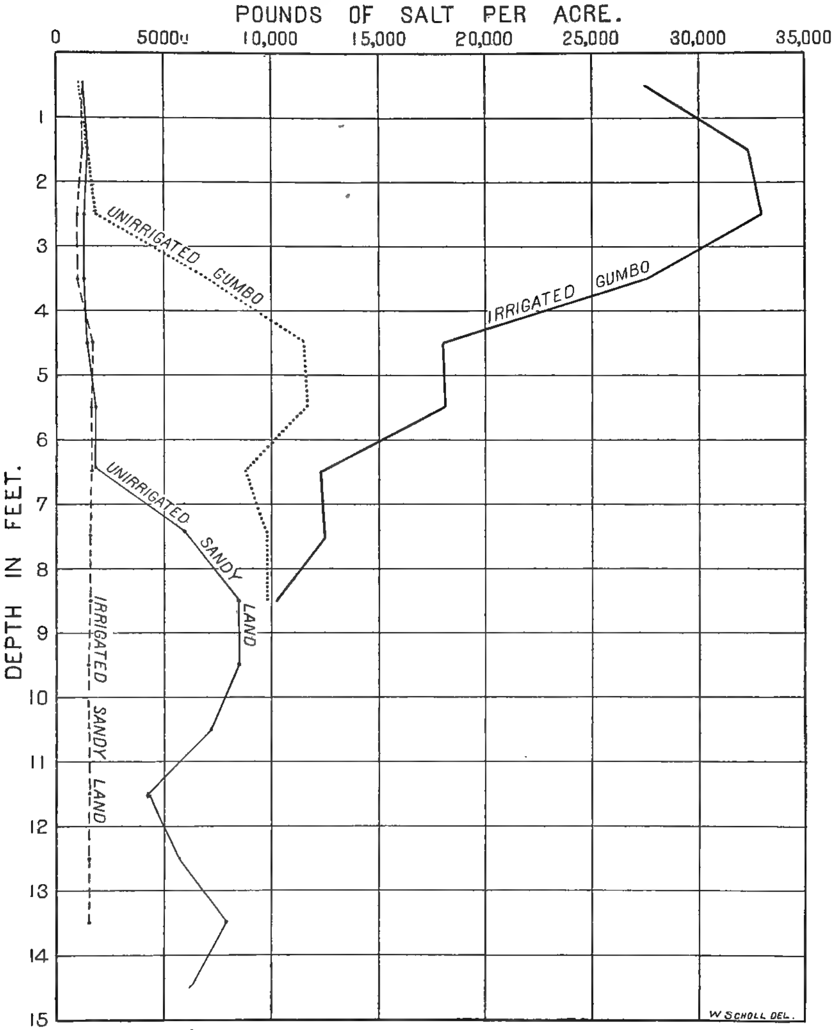


FIG. 3.—The salt content of sandy land and gumbo, with and without irrigation.

layers of the soil. If there is good drainage this excess of salt may be removed altogether from the soil. If the drainage is slow and inefficient, however, or in case of a large excess of seepage waters from higher levels, the water soon accumulates in the subsoil and quickly rises and drowns out all vegetation. If the conditions remain in this way for some time and evaporation is allowed to continue, enormous quantities of salt accumulate in the upper layers of the soil, and the land is finally turned out as an alkali flat.

The accompanying table shows the salt content of an alkali flat in this gumbo soil to a depth of 6 feet.

Amount of soluble salts at different depths in overirrigated gumbo land.

Depth.	Boring 36.	
	Per cent of salt.	Pounds per acre-foot.
0–1 inch	1.023	*a* 2,975
0–1 foot	.757	24,710
1–2 feet	.714	34,570
2–3 feet	.634	21,105
3–4 feet	.612	21,035
4–5 feet	.589	20,965
5–6 feet	.187	6,650

a Pounds in acre-inch equivalent to 35,700 pounds in acre-foot.

It will be seen that the salt has accumulated to enormous proportions in the top 5 feet of the soil. The conditions show that the solution is so strong that a white crust is formed over the surface. However, on account of the absorptive powers of the soil, the solution immediately under this crust and in contact with the soil was only 3 per cent, notwithstanding the fact that the salt ordinarily is very soluble in water. A solution of this strength, however, is entirely too strong for any cultivated crop, and the alkali flat presented a very desolate appearance, as seen in Plate XV.

A line of borings was run from the center of this alkali flat for a mile and a half back to the main canal. A number of borings were made to a considerable depth and salt determinations calculated for every foot in depth in each of these borings. The result of these investigations for the top 3 feet is shown graphically in Plate VIII. In this illustration the span bounded by the curve above the line of 15,000 pounds per acre represents the relative area in which there is an excess of alkali and the amount of this excess. It will be seen that adjoining the canal and for two-thirds of the way down to the alkali flat there is but little alkali, as though the irrigation water had removed the salts from this portion of the land and that they had then accumulated in the alkali flat, which is at a somewhat lower level. These irrigation waters slowly seep through the underground channels down into the natural drainage system, which is represented in this case by the alkali flat on account of its somewhat depressed condition. The salts first appear in these low places in the line of underdrainage and as the evaporation of the water goes on the salts accumulate, gradually extending up and enlarging the alkali flats as the water rises until the level of the surrounding area is reached, when the whole district is abandoned. Along the line represented in this diagram the area around and back from the alkali flat is first-class alfalfa land and the property is considered very valuable, but only three or four years ago the alkali flat itself was considered just as valuable, and the alarming feature of the whole thing is that the owners know that, if these conditions continue, the alfalfa field itself will be ruined and will have to be abandoned in a few years unless very energetic means are taken to arrest the progress of the trouble.

The chances are, of course, that this condition has not arisen from the local application of water at this place. It is possibly a result of injudicious methods of irrigation on the adjoining lands at higher levels. One of the most discouraging features of the whole problem is that the owner of such a tract of land may use the most approved methods of irrigation, and yet be completely ruined by the excessive and injudicious use of water by his neighbor, who may himself escape the injurious effects of his own crude methods, at least for many years after his neighbor has been ruined. In the contemplation of such a problem as is presented in the Yellowstone Valley, therefore, there are certain property rights that may easily be abused, causing very disastrous results to appear upon a neighbor's property. It makes the whole problem very difficult to deal with, especially as it would be extremely difficult to show the source of the trouble and to locate the offending person. It is a problem, however, which will have to be taken up; and if the property owners do not themselves take adequate care of their drainage systems and use intelligent methods of irrigation, some means must be found of compelling them to do so, or to give redress to their unfortunate neighbors.

This accumulation of salts is very harmful in the puddling effect on the soil. The flocculation of the soil grains is broken up and the grains are separated out into their most uniform position, where they offer the greatest possible resistance to the flow of water. This puddling can only be relieved by draining off the water and salts, and this drainage is rendered exceedingly difficult by their presence, so that the reclamation of these alkali flats on the gumbo soil is an exceedingly difficult, slow, and expensive undertaking.

The formation of these alkali flats is in a way an evidence of the effort of nature to correct the faults of our crude system of irrigation. The salts are being carried off into the natural drainage of the country, but the process is very slow and the excess of seepage water and the salts themselves collect in these places on account of the inability of the soil to let them pass as rapidly as the excess of water is supplied. This suggests the only feasible method of reclaiming these lands and, indeed, of preventing the accumulation of the salts which will occur except under the most careful and judicious methods of applying water. In cases like that under consideration, where the damage has already been done, the natural drainage is so slow that it does not afford adequate relief, and in fact is but a sign of impending ruin for a very much larger area. The only way to reclaim the land is to put in an efficient system of drains, preferably of underground tile drains. It is urged against this idea that the land is not worth the cost of the investment in putting in a system of tile drains. This, of course, is an economic problem which is entirely dependent upon conditions of market, transportation facilities, and other commercial considerations. It may or may not be profitable at this time to protect the lands from destruction and to reclaim those that have been destroyed. It may be cheaper to move off into new areas, but the time will come, if it has not already come, when the land in the Yellowstone Valley and in similar situations will be worth the care and expense necessary to protect it from ultimate destruction. The amount of money now invested in the Yellowstone Valley is enormous, and the continuance of prosperity is entirely dependent upon the care which is taken in the methods of irrigating the lands. Property worth thousands of dollars may be ruined in a few years and become utterly worthless. The experience in the valley shows that this has been the case in the past, and there is much uneasiness felt in regard to large areas which show signs of the rapid spread of alkali. (See Pl. XV.)

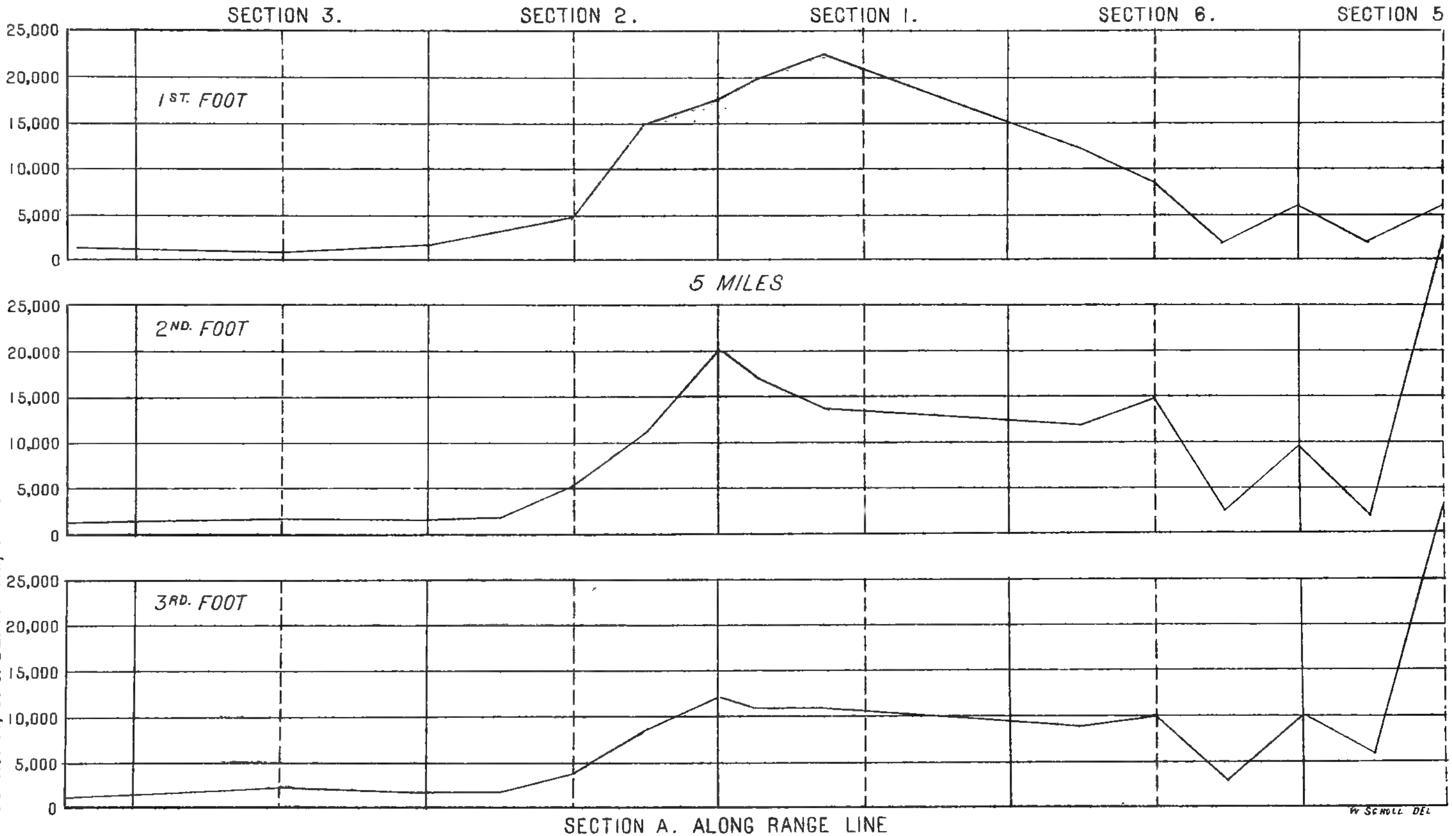
There is abundant evidence that thorough underdrainage will reclaim these lands, and if introduced in time will prevent any such disastrous results as those which have been described. There has been no thorough system of tile drainage tried, but a few efforts have been made to reclaim the abandoned lands by open drains. That these have been efficacious the following investigations will show:

A drainage ditch had been dug in the alkali flat on section 2 and the excess of water had been continuously removed for some time before this investigation was made. A line of borings was made from this ditch back about one-fourth mile to see how the salt content had been changed. The results of the determinations for the top 3 feet is shown graphically on Plate VIII, and the actual determinations are given in the accompanying table, which represents the per cent of soluble salt found at different distances from this ditch.

Salt determinations at different distances from a drainage ditch.

Depth (feet).	Boring 45.	Boring 46.	Boring 47.	Boring 48.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
0-1	0.047	0.054	0.155	0.419
1-2	.030	.066	.164	.253
2-3	.036	.112	.177	.257
3-4	.031	.103	.213	.238
4-5	.045	.109	.191	.275
5-6	.045	.120	.191	.267
6-7	.043	.138	.225	.275
7-8	.043	.162	.237	.337
Average	.040	.108	.194	.290
Total pounds per acre 8 feet deep	11,200	30,280	54,320	81,200

Boring 46 shows the amount of salt about 300 yards from the drainage ditch. The next column shows the amount at about 100 yards from the ditch, while the last column shows the amount closely adjoining the ditch. It will be seen from this table and from graphic representations



SALT CONTENT FROM A LINE OF BORINGS 5 MILES LONG ALONG THE RANGE LINE. THE BLUE COLOR REPRESENTS THE EXCESS OF SALT.

(Plate VIII) how the salts have accumulated at the lowest point of the drainage system and how they are being removed by the drain as the water from the irrigating ditch seeps down and the excess of seepage water is carried off. The amount of salt found at the drainage ditch is already below the 15,000 pounds limit of crop production, while farther out in the alkali flat, under presumably the same conditions as existed at the drainage ditch when it was cut, the amount of salt is upward of 35,000 pounds per acre-foot.

It is easy to show in another way the beneficial effects of under-drainage. The land around Billings is underlaid at a depth of from 6 to 8 feet by a layer of gravel. Within the last few years it has been necessary to construct a ditch around the town of Billings to cut off from the town the seepage waters from the irrigated lands. This ditch is cut to a depth of 6 or 8 feet, so that it is in the gravel through its whole length, and it receives the water from two or three natural draws and all of the seepage water from four or five sections of land. No sewage is allowed to flow into the ditch from the town.

A number of observations were made upon this ditch during the month of June. It was estimated that the average flow of water during this time was about 40 cubic feet per second. Frequent determinations were also made of the soluble salt content of the water flowing in this drainage ditch.

The following table gives the amount of salt found during the month of June:

Examination of drainage water.

	Salt (per cent).	Tons of salt removed per hour.
June 4	0.302	13.6
June 6	.424	19.1
June 7	.422	19.0
June 11	.449	20.2
June 12	.283	12.7
June 13	.481	21.6
June 16	.227	10.2
Average	.370	16.6

It will be seen that the ditch is doing a great work in removing the salt content from the overirrigated lands around the town. At the rate at which the salt was being removed at the time these observations were made, the ditch was removing about 16½ tons per hour. If this rate was continuous, it would drain 1 per cent of salt from the upper 5 feet of about 900 acres of land per year. As a matter of fact, while the ditch rarely if ever stops flowing, the flow is not always as great as during the time of this investigation. Still the figures give some idea of the enormous results which may be accomplished by a judicious system of drainage in the reclamation of these alkali lands and the protection from an undue accumulation of salt and seepage waters.

Plate I (frontispiece) gives a distant view of the town of Billings from the slate ridge over toward the sandstone ridge on the other side of the valley. This portion of the valley has been almost swamped with seepage waters and ruined with the rise of salts. The white crust of alkali shows in the illustration as covering most of this portion of the valley for 3 or 4 miles from the town of Billings. It is through this area that the drain just mentioned has been started. It may be well to state that the water in the main irrigating canal (Pl. XVI) that is taken out of the Yellowstone River about 40 miles above Billings is very free from alkali, the water, therefore, being used for irrigating purposes, although carried for this great distance through the valley, was fresh and free from salts. From all sources, however, where this water was escaping as seepage water it is seen to be loaded with excess of salts, and where free to flow off readily the salts will be carried off instead of accumulating in the alkali flats.

Besides the examination of the drainage ditch around the town of Billings many determinations were made of the salt content of springs and wells. The following table gives the determinations of the salt content from a number of places.

Salt content of springs and wells near Billings.

	Per cent.
Spring on the sandstone bluff	.029
Well on west side of section 2	.119
Spring on west side of section 2	.212
Well on north side of section 2	.309
Spring on north side of section 6	.433
Spring in center of section 5	.437
Well on south side of section 1	.536
Well on north side of section 2	.538

Well water containing more than one-tenth of 1 per cent is ordinarily considered unfit for domestic use. In most of these wells the water was less than 5 feet below the surface of the ground, and the water tasted strongly saline.

It will be seen, therefore, from all of these sources that the water in the soil is charged with this excess of salt. If there is a ready means provided for it to leave the soil, there will be no excess of soluble salts. It would, of course, be unfortunate to depend upon this to carry off the salts from reckless overirrigation, for in removing these salts much valuable plant food may also be lost and the soil in a measure impoverished. It is necessary, therefore, even with a system of efficient underdrainage, to use great care, so that there shall not be more loss through underdrainage than is necessary. It is perfectly evident, however, on the other hand that if these conditions continue and the water rises closer to the surface than it is at present, that the seepage waters and the accumulation of salts together are likely to prove very disastrous over larger areas.

UNDERGROUND MAPPING OF THESE SOIL AREAS.

Having found the source of the alkali salts in the sandstone and slate rocks which border the valley from which the soils of the valley have been derived, and having determined the character of the soils resulting from each class of rocks, the texture and relation of these to the alkali salts, to underdrainage, and to seepage, the next step was to make a detailed examination of such an area as time would permit for the construction of an underground map, which should show the amount and distribution of the soluble salts at different levels below the surface. For this purpose a preliminary line of borings was made for a distance of about 5 miles along the range line, as indicated on the sketch map of the valley. Borings were made at frequent intervals and the amount of salt determined for every foot in depth. Plate IX shows graphically the amount of salt found in the top 3 feet of the soil along the range line. The line goes just beyond section 3 in the sandy prairie above the ditch, and continues throughout section 3 in the same character of soil, in which the amount of alkali is quite small and no larger than is ordinarily found in the soils of the humid regions. Beyond this the heavy gumbo soils prevail, and the seepage waters have accumulated and the salts have accumulated until the whole of section 1 and a part of section 2 are lying out as an alkali flat. This accumulation of salt and the accompanying accumulation of seepage waters which cover section 1 along this range line, is gradually extending and covering larger and larger areas.

A detailed examination was finally made of section 2, over which the ruin caused by the rise of seepage waters and the accumulation of salts was well advanced. The level of standing water was determined as well as the amount of salt to a depth of 10 or 15 feet. From this examination maps have been constructed, several of which are given in this bulletin, illustrating graphically the amount and distribution of salt in the top 3 feet of soil. The depth to standing water is illustrated on Plate X, with contour lines showing the depth in feet from the surface of the ground to the level of standing water at the time of the observations. The other plates represent with contour lines and with different tints different amounts of alkali salts. The green color on Plate X shows the area over which the depth to standing water is less than 2 feet from the surface and over which, for this reason, alfalfa will no longer grow. On the other plates, XI, XII, and XIII, the blue color represents the area containing over .45 per cent, or 15,000 pounds per acre-foot of soluble salts, which is taken as the limit of profitable crop culture. These plates are fully described in another place.

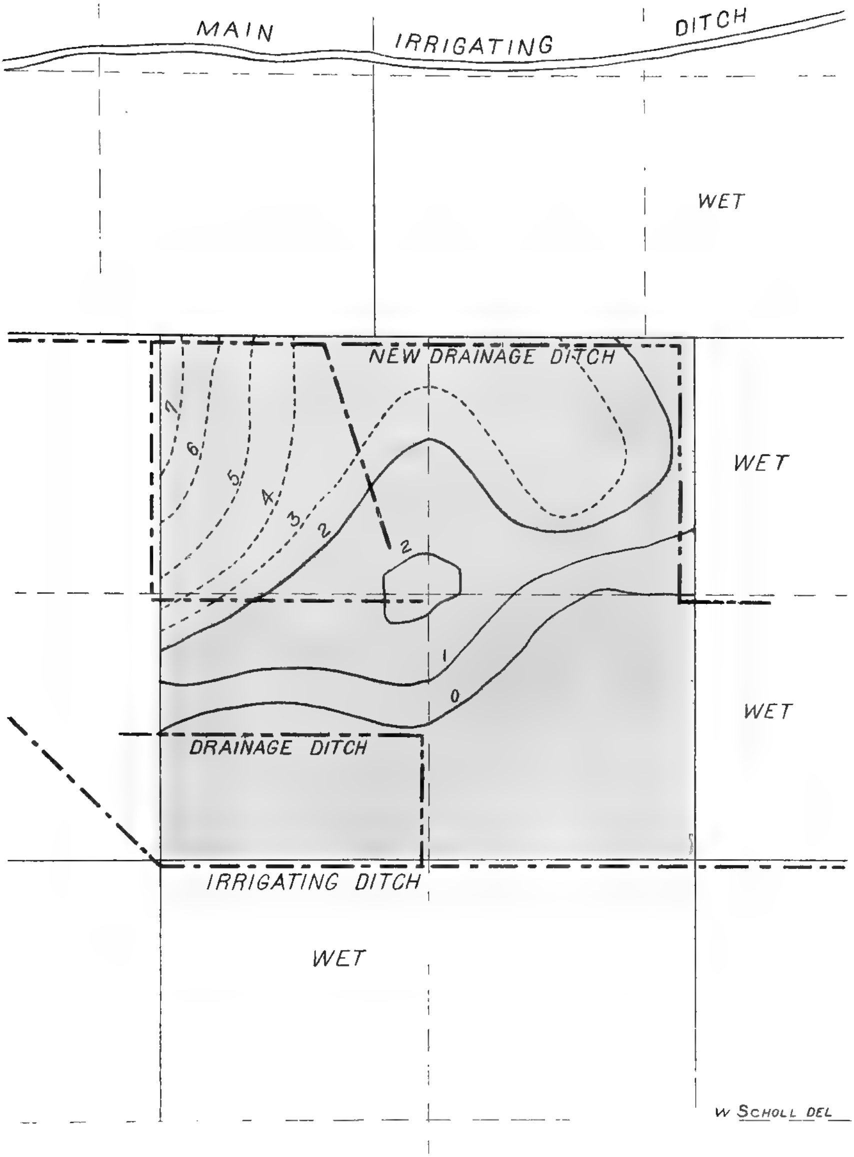
EXPLANATION OF PLATES.

Plate X. This represents the depth to standing water on section 2, upon which alfalfa was gradually dying out. The green color represents the area where the depth to standing water is within 2 feet of the surface of the ground. Over this green area the alfalfa has died out and can no longer be grown. The figures and contour lines indicate the depth to water. The pink area is still in good condition for alfalfa. Much of the green area, especially in the lower section of the area, is a swamp, and efforts have been made to drain it in two places with open ditches. This accumulation of water is entirely due to overirrigation of the surrounding lands. Formerly this whole section of land was a valuable tract of fine alfalfa soil. Before irrigation was introduced into the valley standing water was probably not less than 25 or 30 feet from the surface.

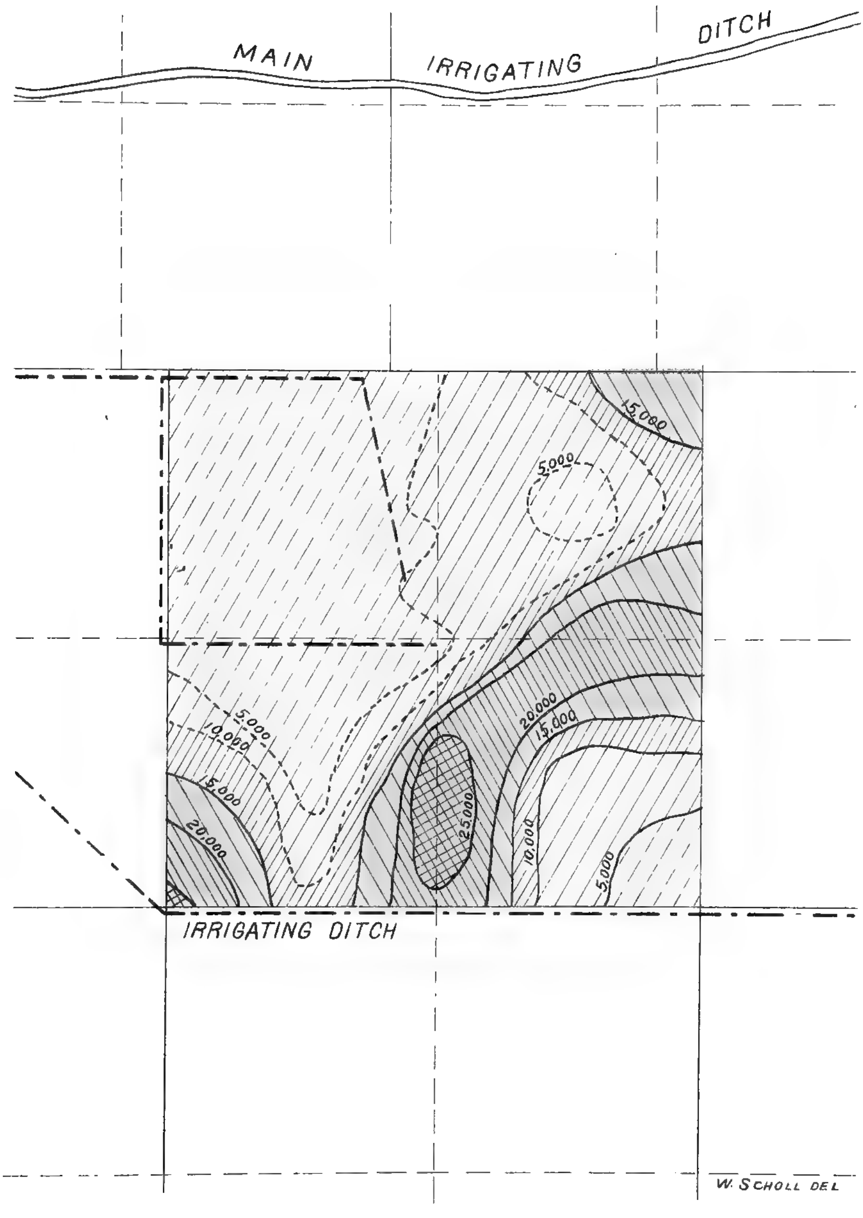
Plate XI. This illustration shows the amount of soluble salts in the surface foot on section 2. The amount of salt is indicated by contour lines, the figures showing the amount of salt in pounds per acre. The pink color is used where there is at present no excess of salt, and the blue color indicates the area in which there is a large excess. The cross-hatching further brings out these areas. It is interesting to observe that the excessive salt content of the soil has not yet spread out so as to cover the whole of the swamp area of the section. It will be seen from Plate XIII that very nearly three-quarters of section 2 is rendered unfit for alfalfa or cultivated crops of any kind, as there is standing water within 2 feet of the surface. Hardly more than a third of this swamp area as yet contains an excess of alkali, but the records for the past few years show that the alkali is increasing and spreading rapidly. It is interesting to note, furthermore, the apparent path of the salt as it occurs in what appears to be a trough, probably due to some peculiarities in the structure of the soil.

Plate XII. This represents the salt content in pounds per acre in the second foot of section 2. This is colored with yellow to indicate no present excess of salt, and with blue to indicate the areas containing an excessive amount of salt. The figures, contour lines, and hatching show clearly the actual amount of salt over different portions of the area.

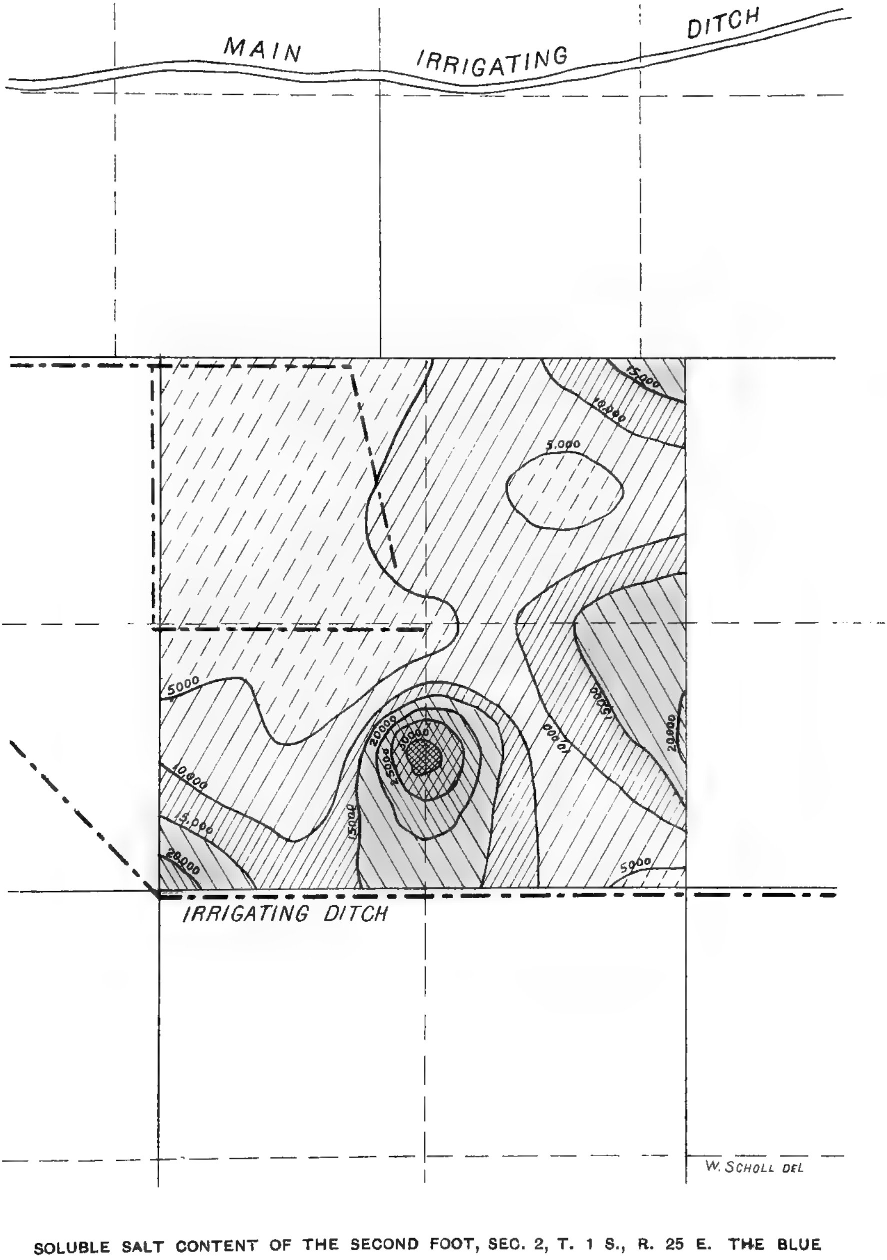
Plate XIII illustrates the amount and distribution of soluble salt in the third foot in depth in section 2. The colors and hatching represent the same features as in the other plates.



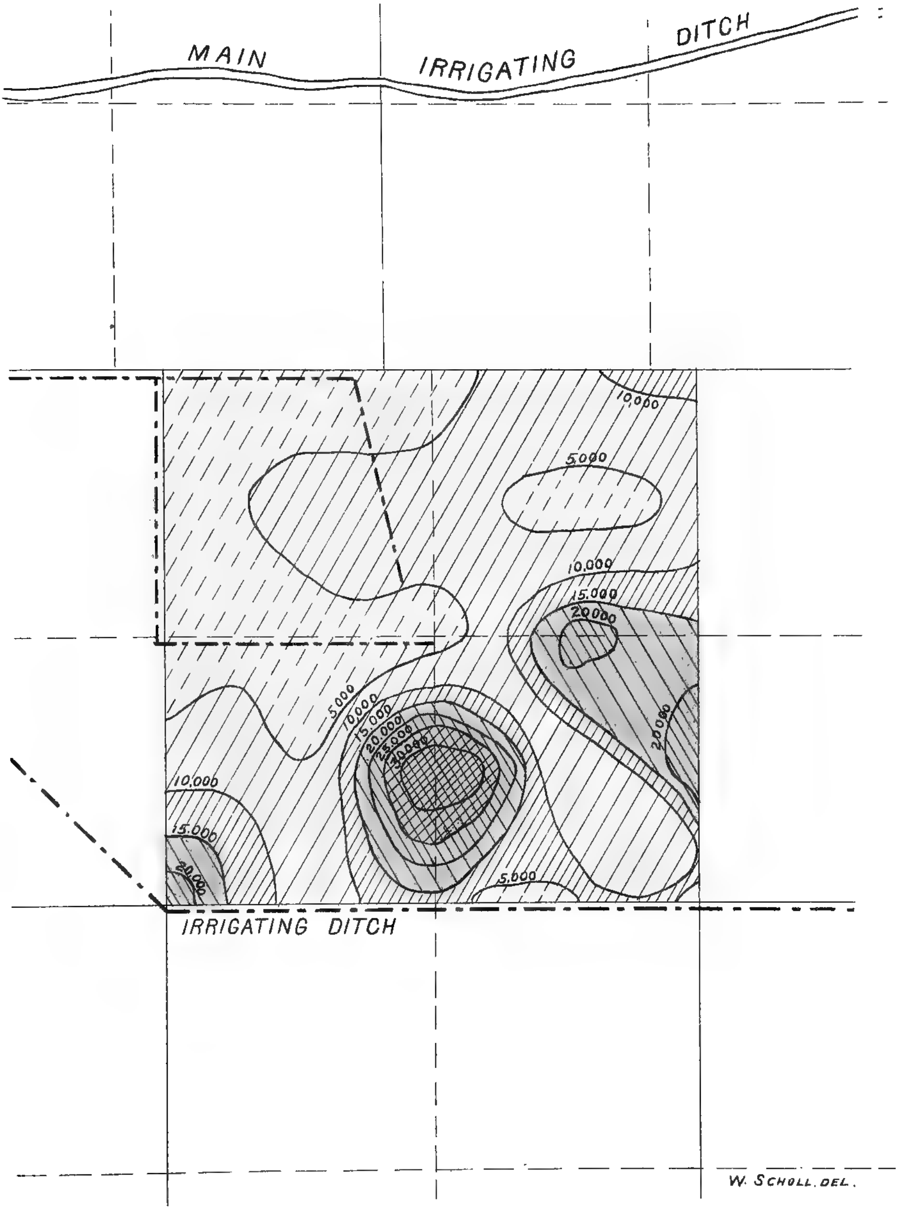
DEPTH IN FEET FROM SURFACE OF GROUND TO LEVEL OF STANDING WATER ON SEC. 2, T. 1 S., R. 25 E. THE GREEN AREA HAS STANDING WATER WITHIN 2 FEET OF THE SURFACE, AND ALFALFA WILL NO LONGER GROW HERE.



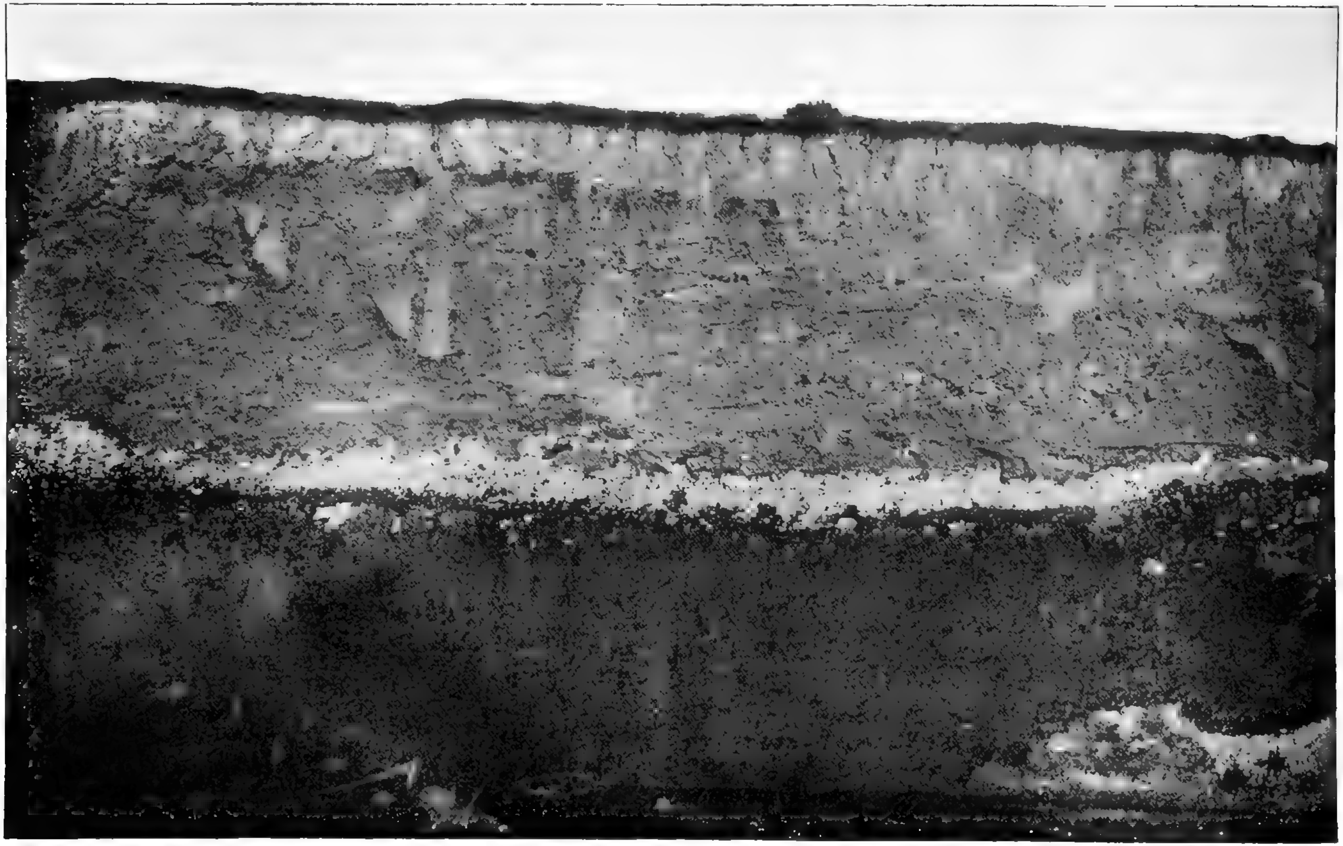
SOLUBLE SALT CONTENT OF THE TOP FOOT, SEC. 2, T. 1 S., R. 25 E. THE BLUE COLOR INDICATES AN EXCESS OF SALTS.



SOLUBLE SALT CONTENT OF THE SECOND FOOT, SEC. 2, T. 1 S., R. 25 E. THE BLUE COLOR INDICATES AN EXCESS OF SALTS.

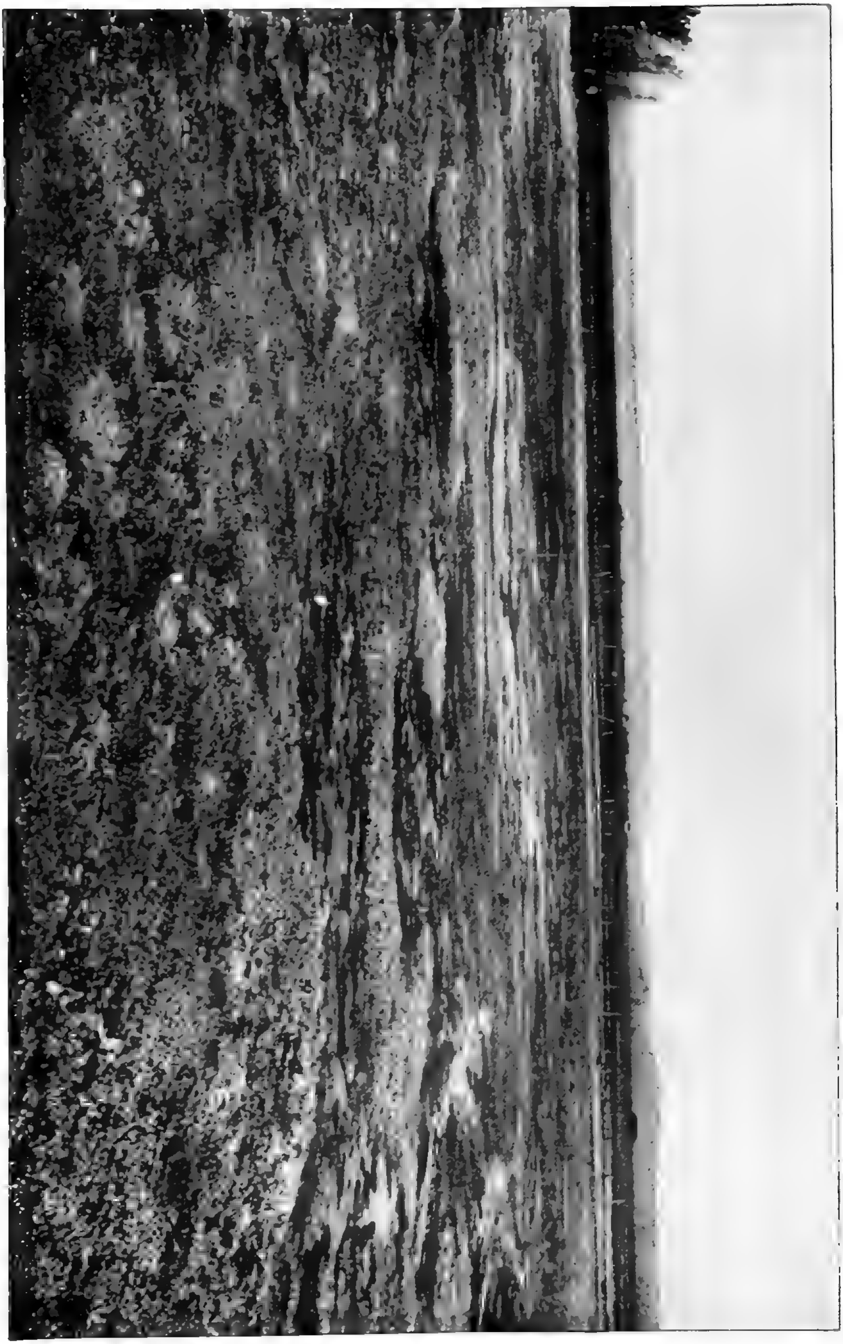


SOLUBLE SALT CONTENT OF THE THIRD FOOT, SEC. 2, T 1 S., R. 25 E. THE BLUE COLOR INDICATES AN EXCESS OF SALTS.



AN EXPOSURE IN CANYON CREEK, ABOUT ONE-FOURTH OF A MILE BELOW THE MAIN IRRIGATING CANAL.

A line of white alkali, about halfway up the face of the canyon shows the line of gravel underlying most of these lands out of which water was flowing at the time the photograph was taken.



ALKALI FLAT ON SECTION 2, FORMERLY A FERTILE ALFALFA FIELD.

Lines B—B, C—C, and the small drainage ditch of Plates X, XI, and XII are in this area.

The value of such underground maps can hardly be overestimated to the owners of the land. It is seen just where the seepage waters and alkali salts are accumulating, from which direction they are coming, and just how drainage systems should be introduced to remove the trouble. They will show that some areas are quite safe for a number of years at any rate, and the maps will indicate other areas which will need careful attention or even energetic efforts in the prevention of or reclamation from damage.

SUMMARY OF THE INVESTIGATIONS AND CONCLUSIONS.

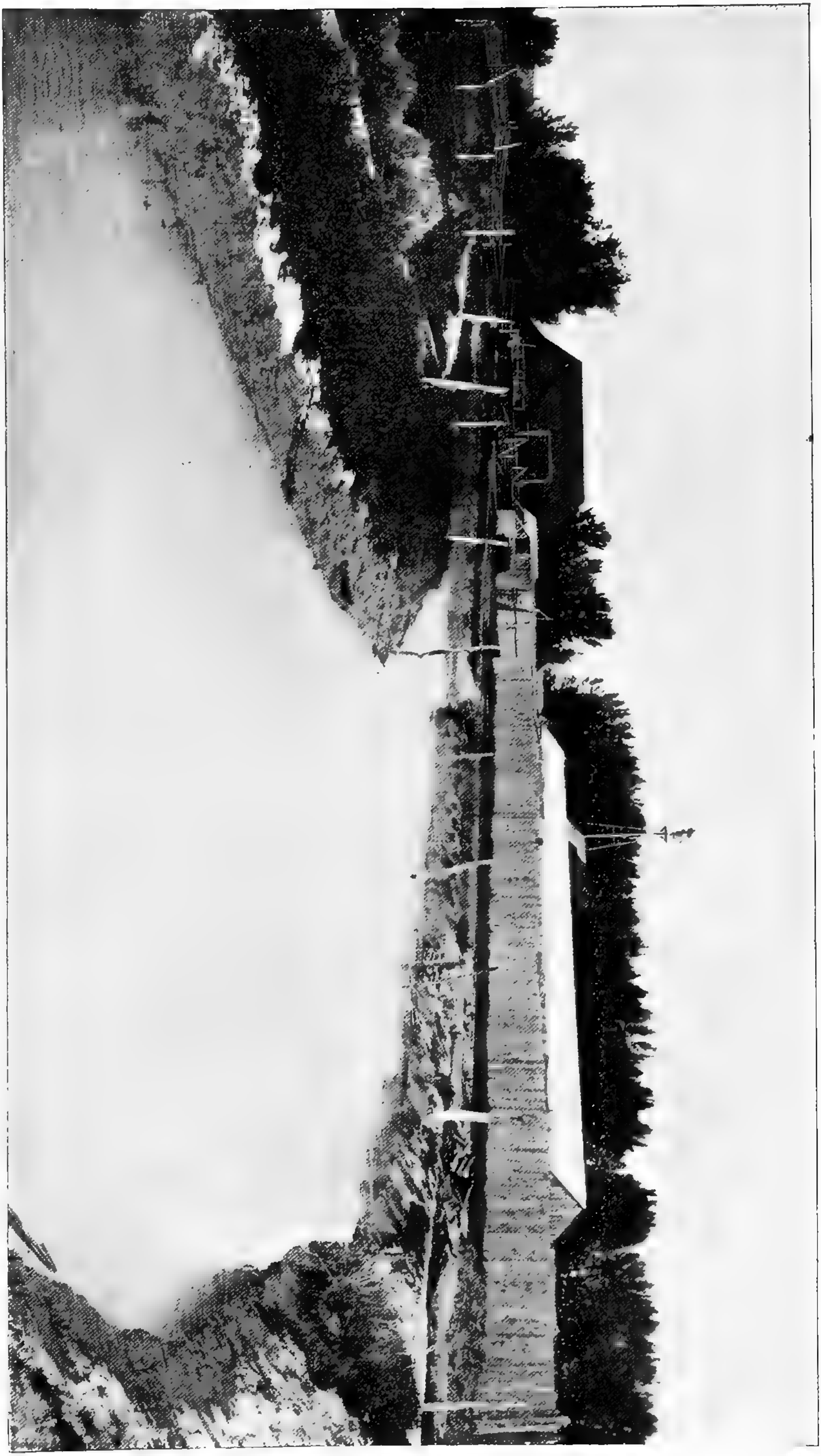
The results of these investigations show that the ultimate source of the alkali is in the sandstone, and particularly in the shale or slate rocks from which the soils have been derived. Before irrigation was introduced the salts were present in rather large amounts, but well distributed throughout the soil, and not in such large quantities as to be injurious to crops. The injury is due entirely to overirrigation, to the translocation and local accumulation of salts by means of seepage waters, and to the imperfect drainage facilities in the compact gumbo soils and the inability of the soils to remove the excess of salts and of seepage waters. The first trouble appears to be due to the seepage waters. This, of course, need not necessarily be so, but it appears to be the case in this locality. The open sandy lands, having better underdrainage, are not likely to be injured by a rise of salts except from an excessive application of water or in the low places in the path of the drainage system, especially when these are underlaid, as they are liable to be, by the heavy gumbo subsoils. The gumbo soil requires great care in cultivation, as it is easily ruined by the accumulation of seepage waters and the subsequent accumulation of salts. There are many areas in the valley, of course, which have still a low or moderate salt content which are probably safe for years to come. There are other areas in which the salts are now accumulating to such an extent as to render the future value of the land very uncertain, while there are still other areas which have gone beyond this stage, and what were once fertile tracts have been thrown out as barren flats. The investigations show, further, the very disturbing fact that the injury need not be due to a local application of water, but to the injudicious application of large quantities of it in remote localities and on neighboring farms over which the unfortunate person has no control and for the effects of which he has at present no redress.

The investigations point clearly to the natural methods of preventing this injury and of reclaiming the lands when once the injury has occurred. There is no question that the injury is due to the translocation and local accumulation of the salts which were formerly well distributed in the soils of the valley. Alkali has only been troublesome here after eight or ten years of irrigation. The trouble is always preceded by an accumulation of seepage waters, followed in a few years by the alkali incrustations on the surface of the land. This evidently points to the necessity of great care in the application of water in the methods of irrigation. This care must be exercised not only for the land which is being irrigated, but for the adjoining lands on lower levels. While a man can overirrigate a sandy tract with practical impunity to himself, he is likely to swamp his neighbor on a lower level. There are involved property rights, therefore, which will come to be recognized and which will have to be taken into consideration in any intelligent and safe system of irrigation.

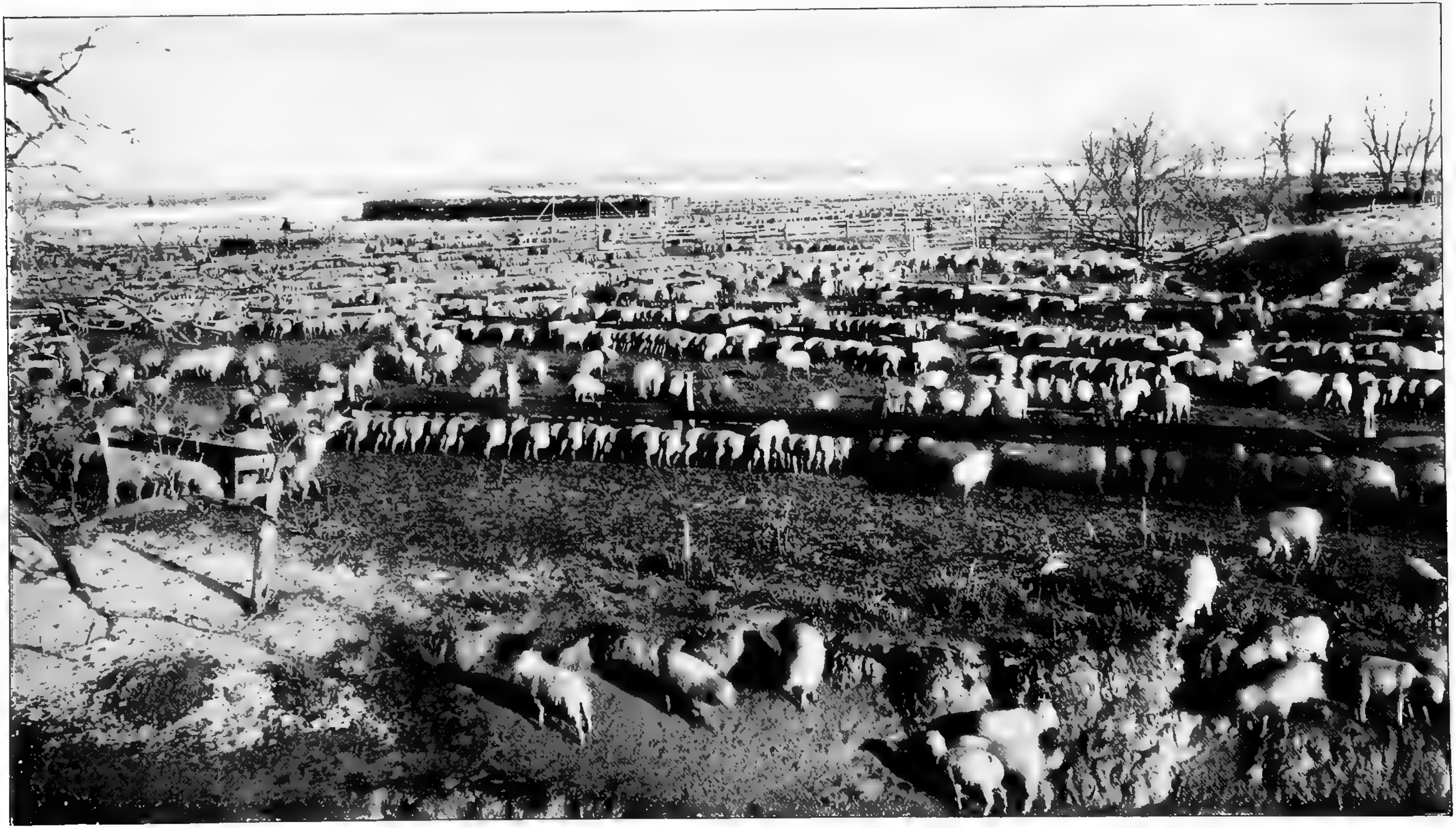
Where the damage has been done, or where the conditions are so imminent that ultimate ruin can be foreseen, the logical method of reclamation is in providing adequate systems of drainage to carry off the excess of water and the accumulated salts. This is expensive, but it is the only thing in this case to hasten the slow processes of nature, which are entirely inadequate in the presence of the present methods of irrigation and of culture. Underdrainage is expensive, but it has amply repaid for the investment in other localities where land is worth no more than in the Yellowstone Valley. Any land which is worth $50 per acre could well afford to be taxed for underdrainage if it is necessary, as in many places in the Yellowstone Valley, to save the investment from utter annihilation. It may be too soon yet to urge an extensive system of underdrainage in the valley, but some small systems should certainly be introduced, if necessary by cooperation, for an object lesson when it is considered necessary and timely to protect against trouble or to reclaim lands already abandoned. The owners will then see that it is feasible to protect their lands and to reclaim, through underdrainage, those that are abandoned.

It has been pointed out already that there are some crops which can stand much larger percentages of alkali than others. It is quite possible that other valuable crops can be found or can be bred which will stand large quantities of alkali, but it is unfortunate, indeed, for a locality like the Yellowstone Valley, which is originally free from alkali, to accept such conditions resulting from their injudicious methods of irrigation and try to find crops which will thrive upon lands which have been unnecessarily injured.

It must not be assumed, however, that a thorough system of underdrainage relieves one from exercising care and judgment in applying water to the land. There is less immediate danger of ruining the land, to be sure, but there are two things to be considered, namely, that an excessive use of water means just so much loss to irrigation and so much less land which can be brought under the ditch, and also that in the removal of these salts by the flow of the seepage waters out through the drainage system large quantities of really valuable plant food are likely to be removed from the soil. The very accumulation of these soluble salts is due to the arid conditions of the climate. The great fertility of the soils results from the accumulation of these salts, and if we introduce



THE MAIN IRRIGATING CANAL; WATER TAKEN OUT OF THE YELLOWSTONE RIVER ABOUT 35 MILES ABOVE THE PLACE WHERE THIS ILLUSTRATION WAS TAKEN.



FEEDING OF SHEEP AND RANGE CATTLE DURING THE WINTER SEASON.

One of the important industries of the valley. It is principally for this winter feeding that the alfalfa and other forage and grain crops are grown.

artificial drainage, which will tax the resources of the soil, we may remove in the course of a generation, or even in less time than this, the accumulated results of the changes of vast geologic ages in the disintegration of rocks. By overirrigation and underdrainage we may remove in a few years the very conditions which contribute to the wealth of the country in the fertility of the soil.

In taking up new land in the Yellowstone Valley the heavy gumbo soils should be underdrained at the time the first irrigation waters are applied to the land. Even if the system of underdrainage is not complete at the start, a sufficient amount of it should be put in to answer the purpose at the beginning, and so arranged that it can be extended and more laterals put in as time goes on and the necessity of it becomes apparent. It is too late to wait until the damage has been done, for the accumulation of salts themselves acts on the heavy gumbo soils and makes them more impervious to water and harder subsequently to drain. Great care must be taken in the application of water. As little as possible should be applied at each time, so that there shall be as little waste as possible to go off as seepage water. The surface then should be thoroughly cultivated, unless otherwise protected from evaporation by alfalfa or other close-growing crops, so as to reduce the loss of water from the surface to a minimum and prevent thereby the accumulation of salts at the surface.

The rise in the level of water in wells must be looked upon with uneasiness and guarded against with great care.

The conditions in the Yellowstone Valley are particularly simple, and the danger from the rise of salts may be easily controlled. These investigations show the cause of the trouble, the actual conditions over a small section of the valley, and point out the logical methods of preventing trouble and of redeeming the land after the trouble has come. The locality is fortunate indeed in having no great excess of alkali in the soils previous to irrigation, as occurs over such large areas in adjoining States. The question involved is a simple problem, well within the control of the intelligent land owners of the valley.

APPENDIX.

List of the borings, with the percentage of soluble salt content of each foot in depth.

(For location of borings, see map, fig. 1.)

	Location.	1 ft.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	10 ft.	11 ft.	12 ft.	13 ft.	14 ft.	15 ft.
1	SW. cor. NE. ¼ sec. 4, T. 1 S., R. 26 E.	0.219	0.193	0.165	0.150	0.148	0.161	0.216								
11	Middle NE. ¼ sec. 4	.102	.513	.279	.167											
12	Middle NW. ¼ sec. 4	.323	.405	.411	.465											
13	Middle W. bound. NW. ¼ sec. 4	.442	.442	.493	.150	.241	.340	.377	0.330	0.296	0.496	0.534	0.282	0.218	0.207	0.192
14	Middle NE. ¼ sec. 5	.226	.704	.755	.785	.802										
15	¼ mi. S. center of N. bound. sec. 5	.037	.044													
16	⅛ mi. west (15), 100′ from draw	.031	.043													
17	Middle N. bound. sec. 5	.167	.904	.938	.809	.581										
18	Middle N. bound. NW. ¼ sec. 5	.050	.053	.160	.072	.074										
19	Bottom of draw, middle NW. ¼ sec. 5	.280	.874	.636												
20	Middle W. bound. NW. ¼ sec. 5	.047	.058	.217	.206	.165										
21	NE. cor. sec. 6, in alfalfa field	.166	.268	.289	.357											
22	Middle N. bound. NE. ¼ sec. 6	.050	.061	.084	.050	.048										
23	Middle N. bound. sec. 6	.250	.425	.285	.209											
24	Middle N. bound. NW. ¼ sec. 6	.350	.333	.253												
25	Middle N. bound. sec. 2	.144	.142	.113	.128	.138	.147	.170	.168	.170	.170	.185	.350	.172	.182	.165
26	Middle N. bound. NW. ¼ sec. 2	.046	.049	.052	.066	.097	.106	.128	.147	.112	.112	.056	.056	.058	.058	.058
27	NW. cor. sec. 2	.038	.045	.044	.051	.060	.051	.064	.070	.049	.049	.072	.072	.072	.072	.072
28	¼ mi. S. (27)	.033	.037	.028	.030	.048	.048	.048	.047	.047	.047	.044	.044	.044	.044	
29	¼ mi. S. (26)	.051	.106	.198	.175	.237	.240	.228	.237	.237	.237					
30	¼ mi. E. (29)	.191	.176	.167	.176	.152										
31	Middle sec. 2	.108	.074	.077	.083	.083	.162	.207								
32	SE. cor. sec. 2	.065	.082	.070	.057	.099										
33	¼ mi. W. (32)	.188	.237	.442	.464	.464	.307	.307	.246	.228						
34	Middle S. side sec. 2	.698	.519	.410	.322	.322	.274									
35	Middle S. side SW. ¼ sec. 2	.343	.371	.257	.629	.257	.257	.235								
36	SW. cor. sec. 2, 1st inch 1.023	.757	.714	.634	.612	.589	.187									
37	¼ mi. N. 36, marsh	.395	.283	.232												
38	Middle SW. ¼ sec. 2	.182	.168	.158												
39	SE. cor. sec. 5	.238	.894	.757	.750	.703	.706	.694								
40	Middle S. side sec. 5	.354	.887	.234	.168	.200										
41	Middle S. half sec. 5, ¼ mi. N. 40	1.028	.967	.853												
42	In cañon trib. to Alkali Creek	.020	.025	.019												
43	¼ mi. W. cemetery edge draw	.230	.542	.257												
44	SW. cor. NW. ¼ sec. 2	.045	.042	.045	.044	.043	.037	.077	.045	.075	.075	.082				
45	¼ mi. E. 44	.047	.030	.036	.031	.045	.045	.043	.043	.038	.038					
46	100 yds. S. 45	.054	.066	.112	.103	.109	.120	.138	.162	.154	.156					
46a	Dup. of 46, 2 ft. away	.074	.065	.064												
47	100 yds. S. 46, 100 yds. N. ditch	.155	.164	.177	.213	.191	.191	.225	.237	.237	.237	.212	.212	.252	.252	
48	5′ N. drainage ditch	.419	.253	.257	.238	.275	.267	.275	.337							

49	50 yds. W. center of flat, ¼ in. N. 34	.792	.920	.944	.792	.519	.519	.357	.357	.292						
50	Center SE. ¼ sec. 2	.260	.200	.168	.203	.198	.198									
51	¼ mi. N., S. bound. sec. 2, ¼ mi. E. 50	.233	.597	.679	.534	.404	.464	.310	.310							
52	Alfalfa dying NW. ¼ sec. 2	.229	.191	.182	.175	.159	.213									
53	¼ mi. E. (31)	.711	.410	.620	.464											
54	Center E. bound. sec. 2	.620	.534	.457	.457	.377	.377	.269	.269							
55	Middle E. bound. NE. ¼ sec. 2	.405	.225	.192	.195	.208	.208	.220	.220							
56	Center NE. ¼ sec. 2	.085	.102	.098	.139	.173	.250	.250								
57	Middle N. bound. NE. ¼ sec. 2	.398	.310	.243	.230	.210	.210	.232								
58	NE. cor. sec. 2	.495	.573	.343	.243	.297										
59	S. bound, sec. 34, across road from boring 25	.213	.223	.243	.253	.297	.297									
60	200 yds. N. (59)	.161	.216	.242	.248	.220	.220	.235	.235	.216	.216					
61	200 yds. S. main ditch	.047	.044	.044												
62	100 ft. above main ditch	.033	.019	.045	.027	.032	.028	.019								
63	Center N. bound. sec. 3	.023	.050	.063	.032	.026	.034	.033	.048	.042	.042	.038	.046	.046	.044	.044
64	NE. cor. sec. 4; prairie	.042	.041	.035	.038	.045	.055	.156	.170	.238	.243	.205	.120	.163	.228	.178
65	Center N. bound. NW. ¼ sec. 1	.565	.487	.336												
66	Center N. bound. sec. 1	.644	.384	.310	.343											
67	¼ mi. S. of NE. cor. sec. 13	.019	.019	.037	.125	.164	.112	.078	.094	.083	.090					
68	Center Hesper farm, sec. 18	.039	.046	.032	.028	.018	.019	.035	.032	.025	.018	.019	.018	.017	.030	.100
69	¼ mi. E. (68)	.036	.027	.019	.050	.057	.047	.050	.071	.077	.075	.063				
70	Unirr. gumbo ¼ mi. S. Hesper farm	.035	.038	.054	.200	.333	.337	.253	.253	.282						
71	Beet patch, Hesper farm	.042	.077	.102	.065	.054	.052	.043								